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Final Report June 1982

AN EXPANSION OF BALFRAM TO INCLUDE EXPLICIT REPRESENTATION OF LOGISTICS FUNCTIONS

By: LOLA C. GOHEEN BERT LAURENCE RICHARD H. MONAHAN

Prepared for:

DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER
BETHESDA, MARYLAND 20084

CONTRACT N00167-80-C-0174

333 Ravenswood Avenue
Menlo Park, California 94025 U.S.A.
(415) 326-6200
Cable: SRI INTL MPK
TWX: 910-373-2046

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SRI Project 2216

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Approved by:

JACQUES NAAR, *Director*
Center for Defense Analysis

DAVID D. ELLIOTT, *Vice President*
Research and Analysis Division

333 Ravenswood Avenue • Menlo Park, California 94025 • U.S.A.
(415) 326-6200 • Cable: SRI INTL MPK • TWX: 910-373-2046

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The Balanced Force Requirements Analysis Model (BALFRAM) is a deterministic, expected value model that permits the rapid determination of the numbers and kinds of balanced General Purpose Forces necessary to carry out specific contingency plans. The original BALFRAM does include consideration of the effects of logistics shortfalls on the effectiveness of combat units. However, there are several shortcomings in the manner in which logistics is modelled within the BALFRAM structure. The research described in this report was directed toward remedying some of these shortcomings. This effort was segregated into two separate components.

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The first component of the research was directed to improving the logistics features of BALFRAM itself. One major improvement was to allow for multiple supply classes. A second major improvement was to allow the user more flexibility in the selection of the transfer function which computes a unit's operability factor, which reflects its combat effectiveness degradation resulting from a supply shortfall in each of the multiple supply classes.

The second component of the research involved the development of a SUPPLY DISTRIBUTION MODULE. This module, which is a separate adjunct to BALFRAM, is a computer program that models the transporting of supplies to the theater area that would be represented within a BALFRAM scenario. Joint usage of BALFRAM and the module will first require a BALFRAM run to establish the requirements imposed on the pipeline providing supplies to the theater area. Then the SUPPLY DISTRIBUTION MODULE would be run to determine the pipeline characteristics necessary to meet these requirements.

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CONTENTS

ILLUSTRATIONS

TABLES

PREFACE

This report documents the analysis and findings of a research project conducted for the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Bethesda, Maryland. The sponsor and technical monitor was M. J. Zubkoff, Code 187, of DTNSRDC. The work was performed under Contract N00167-80-C-0174.

The research was performed in the Center for Defense Analysis (CDA) of the Research and Analysis Division (RAD) of SRI International. J. Naar is Director of CDA, and D. D. Elliott is Vice President of RAD.

R. H. Monahan was project leader. He was assisted by B. Laurence and L. C. Goheen.

I INTRODUCTION AND SUMMARY

A. Introduction

1. General

The primary objectives of the research described in this report were to identify at-sea logistic functions that can be represented within the framework of the Balanced Force Requirements Analysis Model (BALFRAM) and to develop an initial logistics module representing at least one of these at-sea logistic functions. In addition, SRI was to assist DTNSRDC in implementing BALFRAM on their CDC 6000 series computer.

The original BALFRAM was developed at SRI, under sponsorship of the Office of Naval Research, during the period from 1967 through 1974. The model is a deterministic, expected value model that permits the rapid determination of the numbers and kinds of balanced General Purpose Forces necessary to carry out specific contingency plans. It is a flexible technique to be used for modeling the engagement of opposing military forces and for estimating the expected value outcome of such engagements, thus assisting in the evaluation of the relative effectiveness of alternative force levels, mixes, deployments, and utilizations. It provides a unified and balanced approach to force analysis by integrating the simultaneous activities of land, sea, and air forces. It can therefore be used to follow and assess interactions between the component services in their coordinated support of a military objective.

The original BALFRAM does include consideration of the effects of logistic shortfalls on the effectiveness of combat units. However, there are several shortcomings in the manner in which logistics is modelled within the BALFRAM structure. The research described in this report was directed toward remedying some of these shortcomings. This effort was segregated into two separate components: (1) improvement of BALFRAM logistics features, and (2) development of a SUPPLY DISTRIBUTION MODULE.

2. BALFRAM Logistics Improvement

The first component of the research was to improve the representation of the logistics functions internally within the BALFRAM structure. In the original BALFRAM, logistics was represented as a monolithic system delivering equal quantities of indistinguishable supplies along a single pipeline. A combat unit's effectiveness was then degraded linearly according to the ratio of supplies available to supplies required. This approach did not consider different classes of supplies, where a shortfall in one class of supplies (i.e., ammunition) would have a markedly different effect on combat effectiveness than would an equal shortfall in another class of supplies (i.e, personal belongings).

One major improvement made to BALFRAM was to allow for multiple supply classes. Instead of a single supply stream, BALFRAM has been modified to use three different supply classes to determine the combat effectiveness of a specified unit. These three classes could represent bulk POL, ammunition, and other supplies. Combat effectiveness of a specified unit is then degraded independently according to the supply shortfall of each of the three supply classes.

A second major improvement made to BALFRAM was to allow the user more flexibility in the selection of the transfer function which computes a unit's operability factor, which reflects its combat effectiveness degradation resulting from a supply shortfall in each of the three classes of supplies. This computation is now in a parametric form where the user can select a function that determines the shape of the transfer instead of being limited to only a linear transfer function. Three such parametric forms are now available for user option: a polynomial form (which includes the linear transfer function), an S-curve form, and an exponential form. These provide the user with a wide variety of degradation transfer functions that can be used for specific problems.

The end result of this first component of the research effort is an updated version of BALFRAM. This version includes an improved representation of the manner in which the logistics system is modelled.

3. *SUPPLY DISTRIBUTION MODULE Development*

The second phase of the research was directed to the problem of transporting supplies to the theater area to meet the requirements established in a BALFRAM scenario. As a separate adjunct to BALFRAM, a SUPPLY DISTRIBUTION MODULE was developed to address this problem. In BALFRAM, the logistics pipelines are assumed to begin at a supply node (port, major supply depot, seaborne mobile logistics group, or a group of auxiliary supply ships servicing a naval task force). Then, these pipelines are assumed to extend to the combat units to be supplied. Supplies are assumed always available at the supply node, and supply shortfalls occur only if there is insufficient transportation capacity to move them to the combat units. Thus, BALFRAM itself deals with transporting supplies from a supply node and not with acquiring and stockpiling the supplies themselves. In this sense, BALFRAM can first be used to establish the requirements imposed on the pipelines providing supplies to the theater area. The SUPPLY DISTRIBUTION MODULE can then be used to determine the pipeline characteristics necessary to meet these requirements.

The SUPPLY DISTRIBUTION MODULE is a computer program that considers a set of three quasi-independent supply pipelines. Each of these pipelines represent the flow of one of three classes of supplies (bulk POL, ammunition, or other supplies) from a supply source or depot to a remote intermediate point (i.e., a supply node in a BALFRAM scenario) that services a set of user elements. The requirements imposed on the pipelines are dictated by the users' demands, which can change over time in accordance with prespecified contingency events. Pipeline operations are represented by the periodic scheduling of cargo

carriers and their cargo loads. As contingency events occur, pipeline operations are modified to meet the new demands of the users. Because of the time lag involved in adjusting pipeline operations, user demands may not be satisfied during the transition period. Hence, users may need to draw from reserve supplies.

This program monitors the supply levels of the users and the intermediate supply point. The module can be used to examine the extent of user supply shortfalls resulting from unanticipated contingent activities, or it can be used to apriori alter pipeline operations in anticipation of contingencies, thus ensuring sufficient provisioning of users at all times. The module can be used in conjunction with a BALFRAM exercise or, being separate from BALFRAM, it can be used a useful tool for other analyses concerned with transporting supplies to remotely deployed military forces.

4. Report Structure

A summary of the results of this research is presented in the next section of this chapter. The detailed results are discussed in succeeding chapters. Chapter II presents an overview of BALFRAM as it existed before to this research effort. In Chapter III, certain shortcomings of the logistics simulation portion in BALFRAM are identified, and the internal improvements made to BALFRAM to overcome these limitations are described. Chapter IV describes the SUPPLY DISTRIBUTION MODULE that was developed as a separate adjunct to BALFRAM. This chapter includes a detailed description of the module, including the results obtained for a sample problem. Also, this chapter identifies several limitations of the module that could be overcome by expanding the module at a future date. An appendix then follows that portrays the program input formats for the SUPPLY DISTRIBUTION MODULE, defines all of the program nomenclature, and provides a complete listing of the computer program.

B. Summary

1. BALFRAM Overview

BALFRAM is a computer-based, compiler-like model that can be tailored to diverse geographies, force mixes, strategies, tactics, and levels of aggregation. BALFRAM provides an abstract framework within which problems of force requirements and capabilities can be analyzed. It is an event-triggered, time-stepped technique for modeling the engagement of opposing military forces and estimating the expected value outcome of such engagements, thus assisting in the evaluation of the effectiveness of alternative force levels, mixes, deployments, employments, utilizations, and support options. BALFRAM is a two-sided methodology that encompasses Ground, Air, Naval, and Special Purpose Forces.

Geography is represented in terms of nodal points and lines of access between nodes, i.e., a network. The nodal points can represent worldwide, broadly defined geographical areas (battle zones, supply areas) or individual locations such as airbases, ports or key military objectives. Areas represented by a node can range in size from that required for an Army squad to that required for a naval or air battle. The lines of access between nodes represent the paths over which the forces and logistics of both sides must move. These lines and nodes also can reflect strategic movement options such as port or airhead access rights, air space overflight restrictions or contested sea lanes, as well as tactical factors such as military objectives, roads and critical river crossings, and environmental conditions.

Force characteristics within BALFRAM are described by the numbers, types, location, and status of units that each side can ultimately commit during the scenario. Each unit is a notional concept. Unit sizes can vary from representing a company up to representing a theater size force. Furthermore, a unit can represent any of a variety of force types. For instance, a unit can represent a division force equivalent or several

divisions, a formation of aircraft, a ship, or a large naval force. Individual members of a specific unit have similar characteristics such as combat effectiveness, attrition capability, sustainability and mobility.

The initial deployment of all available units and their initial goals are specified as part of the force characteristics. In addition to the initial manner in which available forces are planned to be employed, it is sometimes necessary or desirable to alter deployment policies or mission allocations contingent upon some set of possible circumstances which could occur. These contingent activities provide a model of the operational priorities and movement logic that must govern individual combat units as the scenario progresses. BALFRAM, rather than imposing a fixed set of limited contingency rules, allows the user to specify any unique set of rules for the particular problem and scenario under study.

The fight laws used in BALFRAM are an adaptation of the *Lanchester Laws of Combat*. These laws define the attrition to each side in an engagement as a function of time. They must also permit determination of the time needed for one side to defeat the other. However, BALFRAM is <u>not</u> a Lanchester model per se; rather, it is a modularized simulation that uses the Lanchester laws for some attrition calculations.

Logistics modeling in BALFRAM is accomplished by establishing a set of "pipelines" along which supplies flow to designated units. A pipeline may connect many nodes and supply a large number of units. As a result of enemy interdiction, pipeline capacity may be reduced. The effectiveness of the pipeline supplied units is then reduced in proportion to the shortfall of supplies. Provision is made for pipeline regeneration rates, deployment factors, resupply rate factors, and designation of nodes and units to be resupplied. Logistic pipelines can represent air, sea, or land supply lines and thus accomodate strategic heavy airlift, bulk or containerized cargo ships, or truck convoys. The analyst may generate pipelines for

both friendly and enemy forces and specify which of each side's units are to be employed in pipeline interdiction roles.

The purpose of the logistics feature of BALFRAM is to impair unit effectiveness when logistical capacity will not sustain maximum effectiveness. The main components of the logistics simulation are the logistical transportation units. These units have an order of battle measured in units of transportation capacity, such as convoys, cargo ships, containers, reefers, and the like. Each unit of transportation has a supply capacity. The fighting units have a supply requirement that is specified in supplies per fighting unit. The logistics pipeline is assumed to begin at a supply node (port or major supply depot) and extend to the supplied units. Attrition in the logistics simulation is assumed to affect only the transportation units in the pipeline, not the reserve units or the supply node. Supplies are always available if transportation capacity is available to move them. BALFRAM deals with transporting supplies, and not with acquiring and stockpiling.

Resupply of transportation units occurs at a prespecified rate and begins at a scheduled time. When there are more transportation units available than are required by the pipeline to supply the combat units, the excess are held in the reserve unit until needed. Thus, the reserve units build and hold any surpluses that are protected from attrition. Each logistic pipeline is assigned a pipeline unit, a reserve unit, and a specified set of combat units and nodes to supply. Each logistics pipeline is independent of all other pipelines.

The supply requirements are computed for all assigned combat units when they are at the specified nodes. This is done by multiplying the unit size by the required supply rate. The sum of these requirements is compared with the supplies available. The number of transportation units available is the sum of the units in the pipeline and reserve units. When the available supplies are less than the required supplies, the combat effectiveness of each supplied unit is scaled down to an

appropriate level. The current scaling method in BALFRAM consists of multiplying each combat unit's firepower potential by the proportion of required supplies that are available, a strictly linear degradation.

Another feature of the logistics simulation is to control combat unit deployment as a function of the availability of logistics. Deployment of any combat unit can be delayed until there is sufficient transportation capacity to accomodate the units already deployed, leaving enough capacity to also supply any unit about to be deployed.

BALFRAM has a number of features to select meaningful output, including options for complete battle history, FEBA movement history, logistic throughput and interdiction history, battle node information, and summaries. Also available is a complete description of the input scenario: force structure, deployment, time-phased military objectives, operational and support concepts, and scheduling.

2. Logistics Shortcomings and Improvements in BALFRAM

There is general acknowledgement that lack of logistics support will decrease combat unit effectiveness. However, there is not agreement on the quantitative effects on combat unit potential that would result from logistic support inadequacies of various types, such as supply shortfalls or maintenance system deficiencies. Logistics is not a monolithic system delivering equal quantities of equally needed supplies. The logistics system delivers separate items for a multitude of purposes. These items are generally grouped into classes for ease of management and handling such as bulk POL, ammunition, and other supplies. The effects of shortfalls in these classes on combat potential are markedly different, depending on both the class and the type of unit being supplied. The previous BALFRAM version treats all supplies as indistinguishable and, therefore, of equal effect on the success of a combat unit.

One major improvement in the present version of BALFRAM

is the addition of multiple supply classes. Instead of a single supply stream, BALFRAM has been modified to use three supply classes to determine the combat effectiveness of a specified unit. For example, the three classes could represent bulk POL, ammunition, and other supplies. Each of the classes has independent transportation capacity, regeneration capability, and attrition. Supply shortfalls in the three classes each generate independent operability factors that are combined to compute the total loss of combat effectiveness of the unit. A operability factor is computed for each supply class for each unit supported by the pipeline. Pipelines are defined by the collection of units that are supplied and the nodes where those units must be located to receive those supplies. The operability factor is computed from a transfer function that uses the ratio of supplies available to supplies required.

The second major improvement in the BALFRAM logistics module allows more flexibility in the selection of the transfer function that computes the operability factor from the ratio of supplies available to supplies required for each supply class. This computation has been changed to a parametric form. The user will not be limited to a linear transfer function but will be able to choose a function that determines the shape of the transfer. Three such parametric forms are now available for user option; a polynomial form, an S-curve form, and an exponential form. These provide the user with a wide variety of operability transfer functions that can be used for specific problems.

3. SUPPLY DISTRIBUTION MODULE

A SUPPLY DISTRIBUTION MODULE was developed as a separate adjunct to BALFRAM. This module addresses the problem of transporting supplies to a theater area. BALFRAM can first be used to establish the requirements imposed on the pipelines providing supplies to the theater area. The SUPPLY DISTRIBUTION MODULE can then be used to determine the pipeline characteristics necessary to meet these requirements.

The SUPPLY DISTRIBUTION MODULE is a computer program that considers a set of three quasi-independent supply pipelines, each pipeline representing the flow of one of three classes of supplies (bulk POL, ammunition, or other supplies) from a supply source or depot to a remote intermediate supply point (ISP) that services a set of user elements. An ISP could represent a foreign port, a remotely located supply base, a seaborne mobile logistic force, one or more AOEs in company with a task group, or simply an unattended task group taken as a whole. The user elements could represent foreign-based troops drawing supplies from a foreign port or supply base, a debarked marine force drawing supplies from a sea-based logistic support group, or a task group drawing supplies from underway replenishment ships.

Users are continuously supplied by their ISP, while the ISP is resupplied on a periodic basis by cargo carriers (ships or aircraft) whose cycle time includes transit time, loading and unloading times, preparation time, and a delay time for routine maintenancee and other activity between cruises or flights. User inputs include an initial demand rate, a maximum supply level, a safety supply level, a critical supply level (just enough supplies to enable the user to withdraw and return to a safe haven), and an essentiality priority of the user in relation to other users on the pipeline.

Initially, the users are assumed to be stocked to their maximum supply levels, and an initial pipeline operation is set up so that the ISP can meet all the demands of its associated users. ISP inputs include a maximum storage capacity, an emergency supply level, a critical supply level, and its own supply demand rate. The initial pipeline operation dispatches cargo carriers on a periodic basis so that a cargo carrier arrives and transfers supplies to the ISP just at the time when the ISP's supply level drops to the emergency supply level. Thus, under the initial conditions, user demands are being met, their supply levels remain at their maximum, and the ISP does not have to draw from its emergency supplies. This pipeline

operation continues until a contingency occurs, where a contingency reflects a change in a user demand rate. At this time, the pipeline operation is modified so that the ISP will be capable of meeting the new demand once the new pipeline operation is in effect. In the interim period, several things could occur. If the contingency is an increase in demand then the ISP may have to begin drawing from its emergency supplies at some time. During this interim period, cargo carrier arrivals will be more frequent, since expected shortfalls will have to be recovered. If, during this period, the ISP has to to draw from emergency supplies and cannot satisfy the user's demands (i.e., its supply level would reach the critical supply level before the arrival of the next cargo carrier), then the user supply level rates are decreased in a way that takes into account their essentiality priority numbers. In this case, user supply levels will decrease, and one or more may drop below their safety levels. If this occurs, the affected user's essentiality priority will be assumed at unity, and supply rates will be readjusted. Also, a user supply level may eventually reach the critical level, and, in that case, the user is assumed to withdraw. Because the ISP will no longer have to supply that user, it can increase the supply rates of the remaining users. Also, this decrease in total demand will impose a requirement to modify the planned pipeline operation, which has not yet even stabilized. Furthermore, user withdrawal due to depletion of one class of supplies will also affect the pipelines that serviced that user for the other classes of supplies. This represents the only dependency between the three pipelines.

The pipeline operation continues in the above manner until one of four events occurs: an input-specified duration time has been reached; all users have withdrawn; an ISP's supply level will drop below its critical level before the arrival of the next cargo carrier; or all contingencies have been processed, and each pipeline operation has reached stabilization.

The output of the module consists of four tables for each pipeline. The first table specifies the times and reasons for the occurrence of selected events, such as when a user supply level drops below its safety level, a user withdraws, a cargo carrier arrives at an ISP, and so on. The second table specifies the supply levels of the ISP and the users at the time of occurrence of an event and at predetermined time intervals. The third table just prints out the supply levels at the predetermined time intervals. The fourth table prints out the supply rates of the ISP and users at the beginning of the operation and at each time that at least one of these supply rates changes value. This latter table provides the required inputs to BALFRAM, where one or more of the users could represent supply nodes within a BALFRAM scenario.

This SUPPLY DISTRIBUTION MODULE represents an initial construct of an analytical tool designed to provide a basis for evaluating the distribution of supplies to operational forces engaged in a theater war scenario within the context of BALFRAM. The module design was constrained by the level-of-effort limitations of this research contract. However, it is capable of being expanded in future research efforts to include additional features, such as the following:

- Pipelines servicing more than one ISP
- Movement of users and the ISP as contingency action
- Limited capacity pipelines between users and the ISP
- Emergency pipelines
- Cargo ship limited availability at the supply source
- Concurrent operation with the main BALFRAM.

Expansion of the module to include these features would enhance its usefulness as an analytical tool for evaluating the effectiveness of supply operations in a theater war scenario.

II BALFRAM

A. Overview

1. General

BALFRAM* is a computer-based, compiler-like model that can be tailored to diverse geographies, force mixes, strategies, tactics, and levels of aggregation. BALFRAM provides an abstract framework within which problems of force requirements and capabilities can be analyzed. It is an event-triggered, time-stepped technique for modeling the engagement of opposing military forces and estimating the expected value outcome of such engagements, thus assisting in the evaluation of the effectiveness of alternative force levels, mixes, deployments, employments, utilizations, and support options. BALFRAM is a two-sided methodology that encompasses Ground, Air, Naval and Special Purpose Forces.

2. Scenario Geography

Scenario geography is illustrative of the model's abstraction. Geography is represented in terms of nodal points and lines of access between nodes, i.e., a network. The nodal points can represent worldwide, broadly defined geographical areas (battle zones, supply areas) or individual locations such as airbases, ports, or key military objectives. Areas represented by a node can range in size from that required for an Army squad to that required for a naval or air battle. The lines of access between nodes represent the paths over which the forces and logistics of both sides must move. These lines and nodes also can reflect strategic movement options such as port or airhead access rights, air space overflight restrictions or

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* See References 1-4 appearing at the end of the main body of this report for a list of detailed documentation of BALFRAM.

contested sea lanes. In addition, these lines and nodes can reflect tactical factors such as military objectives, roads and critical river crossing, and environmental conditions. The nodal network can be as detailed or general as required for the problem under consideration.

3. Force Description

Force characteristics within BALFRAM are described by the numbers, types, locations, and status of units that each side can ultimately commit during the scenario. Each unit is a notional concept. Unit size can vary from representing a company up to representing theater size force. Furthermore, a unit can represent any of a variety of force types. For instance, a unit can represent a division force equivalent or several divisions, a formation of aircraft, a ship or a large naval force. Individual members of a specific unit have similar characteristics such as combat effectiveness, attrition capability, sustainability, and mobility. Every unit, whether it be enemy, allied nation, or U.S. main battle force, has at least the following attributes:

1) Unit type - Ground, Air, Naval or Special
2) Unique Unit Identifier
3) Unit Size
4) Index of Combat Effectiveness (ICE)
5) Time at which unit is introduced into scenario
6) Mobility factor to define rate of movement
7) Initial geographic location for unit
8) Geographic location of unit's initial objective.

4. Contingency Logic

As mentioned above, the initial deployment of all available units and their initial goals are specified as part of the force characteristics. In addition to the manner in which available forces are planned to be employed, it is sometimes necessary or desirable to alter deployment policies or mission

allocations contingent upon some set of possible circumstances which could occur. These contingent activities provide a model of the operational priorities and movement logic that must govern individual combat units as the scenario progresses. BALFRAM, rather than imposing a fixed set of limited contingency rules, allows the user to specify any unique set of rules for the particular problem and scenario under study. This method puts the responsibility for creative decisionmaking logic on the user analyst (where, for maximum flexibility, it should rest).

Contingent activities may be specified in many different ways. The logic statements that effect these changes are of the general form: if some condition is true, then perform an action for specified units. The "condition" portion of the statement may be the location of a friendly or enemy unit, the combat effectiveness of a unit, the attrition suffered by either, the arrival or departure of units at a node, or the passage of time. The action portion of the statement can relate to force movements, a specific unit's mission reallocation, or even a change in the characteristics of the forces involved. Contingency logic within BALFRAM provides an extremely powerful means of structuring scenarios and game progression around a wide variety of analytical rules.

5. Engagement Simulation

The fight laws used in BALFRAM are an adaption of the Lanchester Laws of Combat. These laws define the attrition to each side in an engagement as a function of time. They also permit determination of the time needed for one side to defeat the other. However, BALFRAM is not a Lanchester model per se; rather, it is a modularized imulation that uses the Lanchester laws for some attrition calculations. If the user prefers other than the Lanchester laws for a given engagement, either the exogenous fire routines, or a user-developed algorithm may be specified.

BALFRAM contain two basic differential fight laws: the

square law and the linear law. The differential fight laws embody the assumption that two forces, each capable of inflicting attrition on the other, are engaged in battle. In addition, they assume that, although unit casualty-inflicting power may differ, it is known for all units of both forces. Finally, they assume that all opposing units engaged in a battle are within firing range of each other. In addition to the shared assumptions, the square law assumes that each unit knows the location of opposing units and can determine the results of its own fire; hence, it directs its fire only at surviving enemy units. The additional linear law assumptions, in contrast, are that each unit knows only the general area in which opposing units are located and cannot determine the results of its fire; hence, it distributes it fire uniformly over the enemy-occupied area. A mixed law situation, in which the linear law assumptions apply to one force and the square law assumptions to the other, is also possible.

The BALFRAM software permits the user to select the fight law that is applicable to each node at which a battle may occur. Selection should be made on the basis of how well the various fight law assumptions are satisfied and/or on the basis of empirical evidence of applicability.

6. Logistics Simulation

Logistics modeling in BALFRAM is accomplished by establishing a set of "pipelines" along which supplies flow to designated units. A pipeline may connect many nodes and supply a large number of units. As a result of enemy interdiction, pipeline capacity may be reduced. The effectiveness of the pipeline-supplied units is then reduced in proportion to the shortfall of supplies. Provision is made for pipeline regeneration rates, deployment factors, resupply rate factors, and designation of nodes and units to be resupplied. Logistic pipelines can represent air, sea, or land supply lines and thus accomodate strategic heavy airlift, cargo ships, or truck convoys. The analyst may generate pipelines for both friendly

and enemy forces and specify which of each side's units are to be employed in pipeline interdiction roles. Logistics simulation is discussed in more detail in Section C, Model Logistics.

7. Reports

Any model's output should be structured to allow the analyst to examine results at any selected level of detail. BALFRAM has a number of features to select meaningful output, including options for interdiction history, battle node information, and summaries. Also available is a complete description of the input scenario: force structure, deployment, time-phased military objectives, operational and support concepts, and scheduling.

8. User Controls

Integral to the BALFRAM-based contingency force methodology is a set of sensitivity analysis controls to automatically vary key scenario parameters and iterate the game. User-specified multipliers to order of battle, indices of combat effectiveness, exogenous firepower, or even deployment time will produce automatic sensitivity iterations. Similarly, the distribution of forces can be varied by automatically allocating progressively larger percentages of forces from one group of units to another geographically separate group. This process generates an output matrix of scenario results. Another BALFRAM method for automatically generating sensitivity results is to randomize certain input parameters around given input values so that a normal distribution of each input parameter is produced. Scenario results for each input value or set of randomized input values are generated so that the output set can be examined for its distribution. This technique may be used, for example, to determine a distribution of force level input values that will result in a user-specified scenario outcome. As this example shows, scenario outcomes can be stipulated before the game. Outcomes are defined in terms of the difference between the

surviving components of the BLUE and RED units of interest; BALFRAM then performs iterative solutions based on varying initial force levels to converge on the correct force size to produce the stipulated outcome. Based on the assessment of the effectiveness of combat, combat support, or service support forces' contribution to the stipulated outcome, force structuring and scheduling can be determined for any desired outcome. Further, an estimate can be established of the extent of required host nation support and/or cross-service support. This estimate would be an outgrowth of shortfalls in organic force logistic capability. This integral set of sensitivity analysis controls indicates to the analyst the contribution of the force components to meeting the time-phased military objectives. Also, the analyst receives indications of critical constraints, paths, and deficiencies in the concept of operations and candidate force structure.

B. Model Structure and Requirements

1. Hardware Characteristics

BALFRAM is a self-contained set of subroutines that do not support or maintain any external data base or system. The BALFRAM software has been programmed in FORTRAN IV and has run on the Honeywell 6060 computer, the Control Data 6000, and the IBM 4341. It consists of over 10,000 FORTRAN statements, including approximately 50 subroutines. Run times vary from minutes to hours of CPU time, depending on the number of units involved and the scenario complexity.

2. Software Architecture

The basic program is a high level analytical bookkeeping device that, when provided with input values to describe force characteristics and operational logic, will move forces over the defined geography of the scenario. The program will permit the forces to engage, when appropriate, and will

estimate the outcome of these engagements according to attrition computations that have been mathematically defined. The software has been designed with a wide spectrum of military applications in mind; as a result, individual problems to be modeled do not always require that the full capabilities of the system be exercised. To use BALFRAM, a projected real world scenario must be translated into a BALFRAM scenario. This is done by abstracting the geography of the real world scenario into nodes representing geographic locations at which activity may take place and by describing planned and contingent activity through the use of BALFRAM descriptors (inputs). Thus, BALFRAM is not a "model" until a set of descriptors has been assembled to compose a scenario.

As indicated previously, BALFRAM is written in FORTRAN IV. The number of each type of descriptor is limited by DIMENSION sizes in the program. Thus, the maximum problem size depends on the memory size of the host computer and whether this size is fixed, such as in partitions or a virtual memory. BALFRAM also creates intermediate disk files that must be accomodated.

The BALFRAM documentation contains block diagrams of overall logic, flow charts for all BALFRAM subroutines, the subroutine calling structures, definition of the contents of files and common block arrays, and error messages.

C. Model Logistics

A LGINTDIC (logistic interdiction) card set is used to describe each logistic pipeline of the BALFRAM scenario and to include the effects of reduction of pipeline capacity as a result of interdiction. Provision is made for pipeline regeneration rates, deployment factors, resupply rate factors, and designation of nodes to be resupplied. Each logistic pipeline can be represented by specifying a (pipeline) node, a ground, air, or naval unit (termed a pipeline unit), and a ground, air, or naval reserve unit (termed a pipeline reserve unit). The node contains

the pipeline unit, and interdiction can only occur there. As this unit is attrited, components are instantaneously transferred to it from the pipeline reserve unit. Pipeline regeneration is simulated by increasing the components of the pipeline reserve unit at a user specified time varying (regeneration) rate. For example, if destroyed cargo ships can be replaced at the rate of half a ship per day, starting 30 days after scenario commencement, the regeneration rate would be 0.0 from 0 to 30 days and then 0.5.

Throughput capacity (or supply delivery rate) of each pipeline unit component is equal and specified in units of weight (usually tons) per unit of time. The nodes to be supplied by each pipeline are specified, as are the units that will be replenished or provisioned for deployment. Each unit to be resupplied must be given a resupply factor indicating the quantity of supplies required, per unit time per component, to prevent unit firepower from being degraded by logistic shortfall. Similarly, each unit to be provisioned for deployment can be provided with a deployment factor. This factor specifies the supplies required by each component of each specified unit before that unit can be deployed. If the pipeline is unable to convey sufficient supplies to the unit by its scheduled time of deployment, deployment is delayed until the required quantity of supplies is provided.

Pipeline throughput capacity is a function of interdiction, regeneration rate, and the number of components in the pipeline unit and reserve. When pipeline throughput capacity is inadequate to satisfy the needs of the supplied units, unit firepower effectiveness is degraded by an operability factor varying directly with the shortfall of supply delivery rate. This operability factor is determined as follows:

$$OF = \min\left\{\frac{PTC}{QS},\ 1\right\} \qquad \text{(II-1)}$$

where PTC is the pipeline throughput capacity and QS is the quantity of supplies required per unit time by all units being supplied.

D. Description of Model Attrition

The degradation of unit firepower effectiveness due to logistic shortfalls is modeled within the fight laws for homogeneous forces in BALFRAM. Suppose that at node n, there are two units in combat and exogenous firepower is contributed by one unit on each side. Let FS(t) and ES(t) represent the number of surviving components of the friendly and enemy units, respectively, at time t. The square fight law of enemy attrition is given by

$$\frac{dES(t)}{dt} = -FA \bullet FS(t) - FEF \qquad \text{(II-2)}$$

and the linear fight law of enemy attrition is given by

$$\frac{dES(t)}{dt} = -FA \bullet ES(t) \bullet FS(t) - FEF \qquad \text{(II-3)}$$

where FA is the friendly attrition coefficient and FEF is the friendly exogenous firepower parameter. These parameters are composed of multiplicative factors as indicated in Eq. (4) and (5) below:

$$FA = FFB \bullet FOF \bullet FICE \qquad \text{(II-4)}$$

where FFB is the friendly force base attrition factor. FOF is the friendly unit operability factor due to logistic shortfall (as given by Eq. (II-1) for friendly units), and FICE is the friendly unit index of combat effectiveness;

$$FEF = EFE \bullet CP \bullet FOF \qquad \text{(II-5)}$$

where EFE is the exogenous firepower effectiveness coefficient, and CP is a constant of proportionality that depends on the method of computation used to compute EFE. This method of computation is determined by a user-set code. The model permits EFE to be any of the following:

- A constant.
- Directly proportional to the friendly order of battle at a specified node.
- Directly proportional to the order of battle of a specified friendly unit.
- Directly proportional to the friendly order of battle at a specified node.
- Directly proportional to the friendly order of battle at a specified node and to the enemy order of battle at a specified node. The two nodes are usually different, but need not be.
- Directly proportional to the friendly order of battle at a specified node and the order of battle of a specified enemy unit.
- Directly proportional to the friendly order of battle at a specified node and to the enemy order of battle at the node previously specified and at some other specified node.
- Directly proportional to the friendly orders of battle at two specified nodes and the enemy order of battle at a specified node.
- Directly proportional to the order of battle of a specified friendly unit, the friendly order of

battle at a specified node, and the enemy order of battle at a specified node.

- Directly proportional to the friendly order of battle at a specified node and the enemy orders of battle at two specified nodes.

- Directly proportional to the friendly order of battle at a specified node, the enemy order of battle at a specified node, and the order of battle of a specified enemy unit.

- Directly proportional to the friendly orders of battle at two specified nodes.

- Directly proportional to the friendly order of battle at a specified node and the order of battle of a specified friendly unit.

The dimensions of EFE and CP depend on the computation method specified for EFE. Dimensions of exogenous firepower effectiveness coefficients are discussed in detail in BALFRAM User Manual, Appendix D, "Computation of Exogenous Firepower Effectiveness."

For the general case, where there are several units on each side at a given node, the computations of enemy attrition follow the same above pattern. However, the representations of the coefficients and parameters are much more complicated. In addition, the fight laws of friendly attrition parallel those of enemy attrition.

E. Summary

In summary, BALFRAM provides a unified or balanced approach to force analysis by integrating the simultaneous activities of land, sea, and air forces. It can be used to follow and assess interactions between the component services in their coordinated support of a military objective. The model also includes optional provisions for statistical sensitivity analyses to quantify the relationship between model input and model output. BALFRAM is constructed so that the user defines the problem or scenario of interest from an operational standpoint and

translates it into BALFRAM terms. The user also provides the operational logic (strategy and tactics) that will be applied to the situation and translates this logic into BALFRAM terms. The translations are done through specific user inputs that assemble the appropriate components of the BALFRAM program. Using the BALFRAM software as a tool, the user constructs, with output feedback, a notional model that embodies his abstraction of the real world process. Even after the initial model construct has been completed, modifications can be effected as insights into a particular problem are obtained. Subsequent sensitivity analyses and tradeoffs can be made. This iterative feedback process enables the user to construct a BALFRAM-based model that has analytical relevance to military contingency planning problems as the user perceives them.

III IMPROVED BALFRAM LOGISTICS

A. Logistics Representation in BALFRAM

The purpose of the logistics feature of BALFRAM is to impair unit effectiveness when logistical capacity will not sustain maximum effectiveness. The main components of the logistics simulation are the logistical transportation units assembled into pipeline units and their associated reserve units. These units have an order of battle measured in units of transportation capacity, such as convoys, cargo ships, containers, reefers and the like. Each unit of transportation has a supply capacity such as tons per convoy or cargo ship. The fighting units have a supply requirement that is specified in supplies per fighting unit. All of these rates are actually expressed in BALFRAM as rates per time unit (i.e., tons per day or tons per truck per day).

The logistics pipeline is assumed to begin at a supply node (port or major supply depot) and extend to the supplied units. Attrition in the logistics simulation is assumed to affect only the transportation units in the pipeline, not the reserve units or the supply node. Supplies are always available if transportation capacity is available to move them. BALFRAM deals with transporting supplies, not with acquiring and stockpiling.

Resupply of transportation units occurs at a prespecified rate and begins at a scheduled time. When there are more transportation units available than are required by the pipeline to supply the combat units, the excess are held in the reserve unit until needed. Thus, the reserve units build and hold any surpluses that are protected from attrition.

Each logistics pipeline is assigned a pipeline unit, a reserve unit, and a specified set of combat units and nodes to supply. Each logistics pipeline in BALFRAM is independent of all

other pipelines. The supply requirements are computed for all assigned combat units when they are at the specified nodes. This is done by multiplying the unit size by the required supply rate. The sum of these requirements is compared with the supplies available (i.e., number of transportation units available multiplied by the supply capacity per unit). The number of transportation units available is the sum of the units in the pipeline and reserve units.

When the available supplies are fewer than the required supplies, the combat effectiveness of each supplied unit is scaled down to an appropriate level. The current scaling method in BALFRAM consists of multiplying each combat unit's firepower potential by the proportion of required supplies that are available. This proportion is limited to values between 0.001 and 1.0.

Another feature of the logistics simulation is to control combat unit deployment as a function of the availability of logistics. Deployment of any combat unit can be delayed until there is enough transportation capacity to accomodate the units already deployed, leaving enough capacity to also supply any unit about to be deployed. Units already deployed have first priority on any supplies. The rate required for deployment can be specified as different from the regular combat support rate to accomodate predeployment stockpiling. When there is a conflict between a unit reaching its deployment time and a unit that has held up deployment for lack of supplies, the latter unit will be deployed first.

B. Shortcomings of Logistics Simulation

There is general acknowledgement that lack of logistics support will decrease combat unit effectiveness. However, there is not agreement on the quantitative effects on combat unit potential that would result from logistic support inadequacies of various types, such as supply shortfalls or maintenance system deficiencies. This was considered in the development of the

logistics simulation within BALFRAM. It was felt that a generalized logistic effects model with flexibility of parameter selection was better than ignoring logistic effects altogether. At least, the sensitivity of outcomes under variations of logistics could be examined, even if absolute outcomes could not be estimated. In an aggregated model such as BALFRAM, this strategy appeared reasonable, but there are some areas where potential improvements can be made.

Logistics is not a monolithic system delivering equal quantities of equally needed supplies. The logistics system delivers separate items for a multitude of purposes. These items are generally grouped into classes for ease of management and handling, such as bulk POL, ammunition, and other supplies.

The effects of shortfalls in these classes on combat potential are markedly different, depending on both the class and the type of unit being supplied. The predecessor BALFRAM version treats all supplies as indistinguishable and, therefore, of equal effect on the success of a combat unit. As a first order approximation in an aggregated model, this provides the ability to examine logistics effects.

The relation between the shortfall of supplies and the change in combat effectiveness of a supplied unit is another area of conjecture. A 10% shortage of ammunition may reduce unit effectiveness by 20% by causing the inability to fire and maneuver. However, a 10% shortage in personal supplies may only cause a 2% reduction in unit effectiveness as existing supplies are used beyond the normal point of retirement. This difference in effect would argue against a single class of supplies, while it would argue for separate transfer functions relating shortfall in supplies to reduction in combat effectiveness. These functions should be described parametrically and be selectable for user sensitivity studies.

The existing BALFRAM logistic mode does not stockpile supplies, but it does stockpile the means for delivering the supplies. The logistics depots are assumed to always have

adequate supplies, and the constraint is on the delivery means. Actual logistic systems are sensitive to both factors. Shortages in either factor choke the supplies to the combat units and affect combat capability.

The current logistics simulation assumes that the supplies are instantaneously delivered (within the program time unit) to the combat units. Only the capacity constraints are checked for validity. Thus, when unit size or supply requirement rates change, there is not the lag time that there would be in an actual supply system. This simplification reduces the complexity of the programming logic. Users must be aware that the exact physical flow of supplies is not simulated in BALFRAM.

C. Logistics Improvements to BALFRAM

One major improvement for BALFRAM is the addition of multiple supply classes. Instead of a single supply stream, BALFRAM has been modified to use three supply classes to determine the combat effectiveness of a specified unit. For example, the three classes could represent bulk POL, ammunition, and other supplies. Each of the classes has independent transportation capacity, regeneration capability, and attrition. Supply shortfalls in the three classes each generate independent operability factors that are combined to compute the total loss of combat effectiveness of the unit.

An operability factor is computed for each supply class for each unit supported by the pipeline. Pipelines are defined by the collection of units that are supplied and the nodes where those units must be located to receive those supplies. The operability factor is computed from a transfer function that uses the ratio of supplies available to supplies required.

Individual supply class shortfalls are used to compute operability factors. Let i generically denote a supply class and R_i denote the ratio of supplies available to supplies required for the ith supply class relative to a particular combat unit, then the operability factor for that unit can be represented as

follows

$$OF_i = f_i(R_i) \qquad \text{(III-1)}$$

where f_i denotes the particular effectiveness operability transfer function used for supply class i (the types of transfer functions now allowable in BALFRAM are described later on in this section). For a given combat unit, these factors must be combined to produce a single effect on the unit's combat potential. The operability factors for each class of supplies are multiplied together to compute a unit operability factor (OF) that is to be used to reduce the unit's combat potential. Thus,

$$OF = f_1(R_1) \bullet f_2(R_2) \bullet f_3(R_3) \qquad \text{(III-2)}$$

The manner by which the operability factor is used in the attrition equations of BALFRAM is described in Section D of Chapter II.

A second change in the BALFRAM logistics module allows more flexibility in the selection of the transfer function that computes the operability factor from the ratio of supplies available to supplies required for each supply class. This computation has been changed to a parametric form where the user can select multiple transfer function forms. This way, the user is not restricted to a linear transfer function. In addition to choosing the basic function, the user also provides equation coefficients that give a specific shape to the basic function. The three basic equational forms currently implemented are as follows, where R is the ratio of supplies available to supplies required, OF is the supply operability factor of the combat unit, and a and b are user-specified function parameters:

- Polynomial Form

$$OF = R^b \tag{III-3}$$

- S-Curve Form

$$OF = \begin{cases} a-a \bullet \left(\frac{a-R}{a}\right)^b & \text{if } R < a \\ a+(1-a) \bullet \left(\frac{R-a}{1-a}\right)^b & \text{if } R \geq a \end{cases} \tag{III-4}$$

- Exponential Form

$$OF = \frac{1-e^{aR^b}}{1-e^a} \tag{III-5}$$

Examples of the shapes of these transfer functions are presented in Figures III-1 to III-3, respectively. Note that, in each case, the operability factor is zero when R is zero and unity when R is unity. The previous linear transfer function is the degenerate case of the polynomial form with b equal to 1.

D. Implementation Strategy

BALFRAM is a large, complex FORTRAN program. Because it was not implemented on a virtual storage computer, the program must be divided into overlays or executable modules that will fit within memory limits. BALFRAM implements the individual descriptor cards in a modular fashion through individual subroutines. Data communication is through COMMON statements and intermediate disk files for storing model status after initialization. The disk files permit running iterations without reinitializing the model.

Any logic changes must fit within the existing structure of

Equation: $OF = R^b$

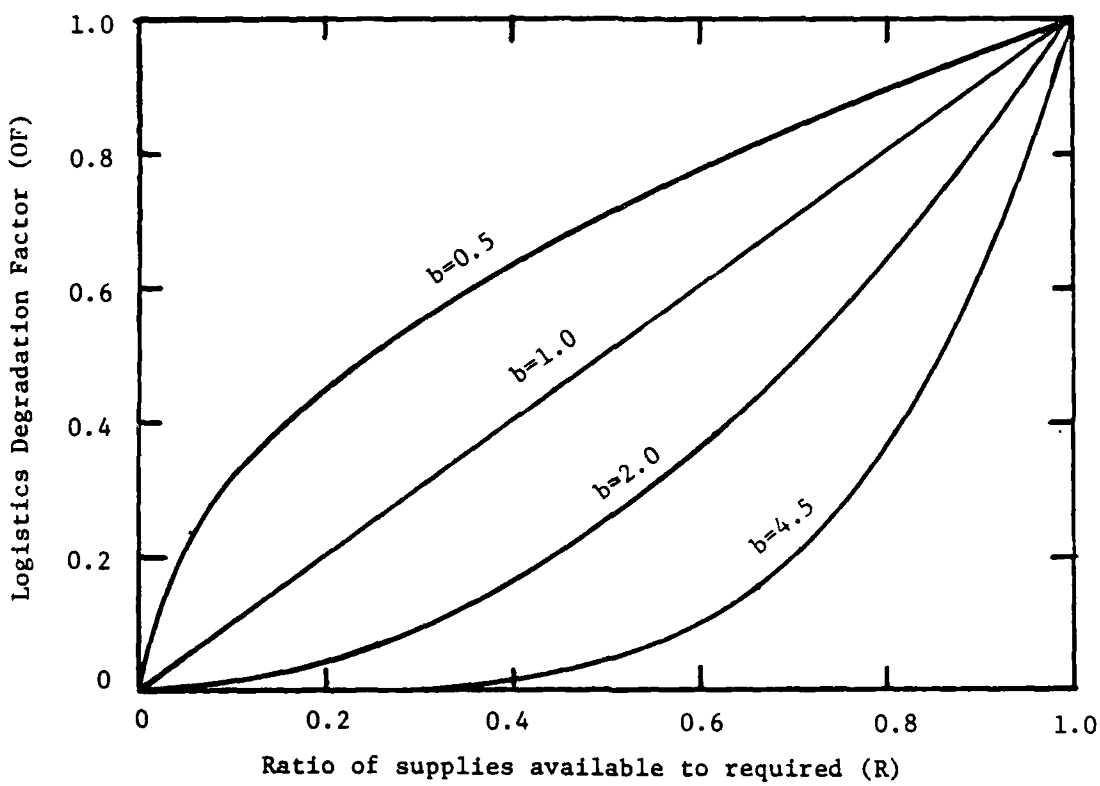

Figure III-1. POLYNOMIAL LOGISTICS TRANSFER FUNCTION

$$\text{Equation:}\quad OF = \begin{cases} a - a \bullet \left(\dfrac{a-R}{a}\right)^b & \text{if } R < a \\ a + (1-a) \bullet \left(\dfrac{R-a}{1-a}\right)^b & \text{if } R \geq a \end{cases}$$

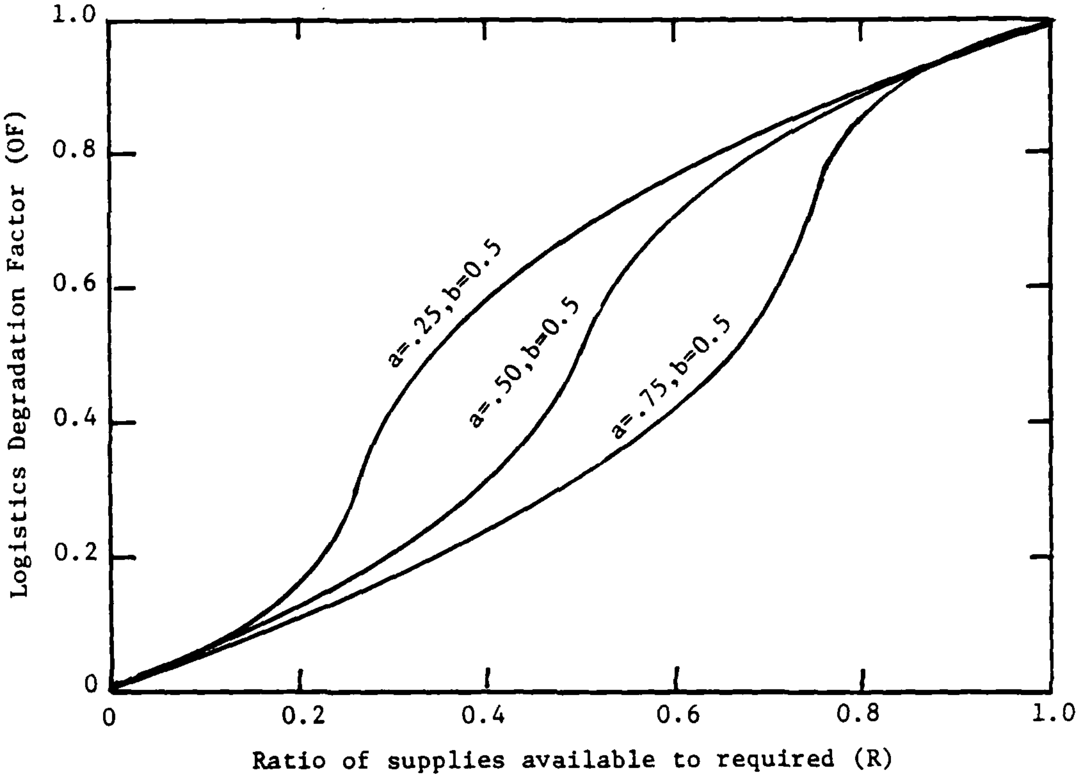

Figure III-2. S-CURVE LOGISTICS TRANSFER FUNCTION

Equation: $OF = \frac{1-e^{aR^b}}{1-e^a}$

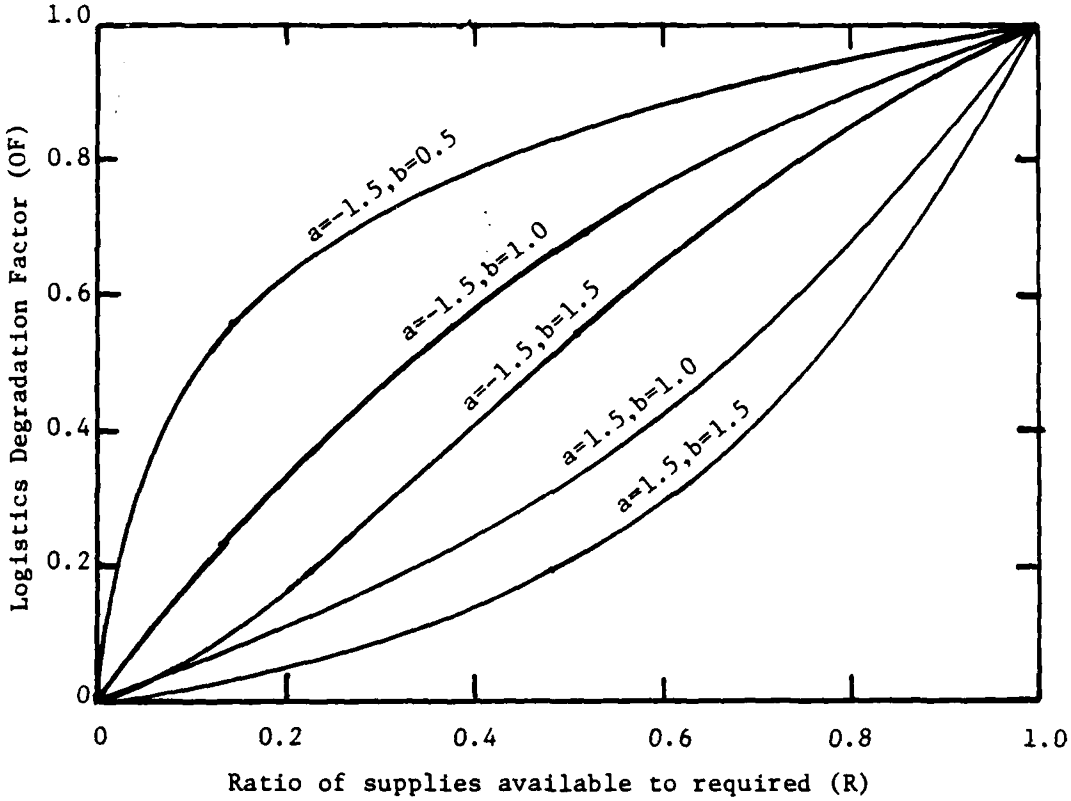

Figure III-3. EXPONENTIAL LOGISTICS TRANSFER FUNCTION

BALFRAM if changes are to be made economically. Changing the program structure substantially would increase the cost of program maintenance and future updates by requiring large amounts of new documentation. Other organizations still use BALFRAM, and it is desirable that changes be compatible with the existing BALFRAM input so that existing data bases can be run with any new program versions.

These factors imply that any changes should not increase data storage or change input formats, if possible. New features should use the same input formats and substitute new data for old wherever possible. Such changes can eliminate the need for changing the input module and its associated COMMONs. Changes are made in the subroutines that implement the descriptor logic by reinterpreting the definition of the existing data and adding new subroutine logic to perform the new functions.

Using this conservative approach for the logistic changes described above resulted in loss of one previous feature and rearrangement of data on the LGINTDIC cards. To have the needed data elements to describe the characteristics of the three pipelines, one feature was eliminated. That was the ability to change the regeneration rate of the transportation capability as a function of time. In the single class case, this feature permitted specification of three times and the regeneration rates that would be effective as of the associated time. In this way, the regeneration rates could reflect changes in supply capabilities at three times during the scenario.

However, it is possible to achieve the effect of increasing the number of transportation elements in the pipeline and reserve units with the new three-class logistics. The Parameter Change (PARMCHNG) card permits changing any of several unit parameters at a specific time during scenario execution. One of the parameters that may be changed is the order of battle (size of a given unit). The PARMCHNG card can increment (or decrement) the unit size. Thus, while the regeneration rate itself cannot now be changed, the size of the unit could be incrementally changed

at regular intervals to reflect a change in rate. Although more cumbersome, this process still allows changing the transportation capacity of the pipeline and reserve units of each class independently.

The new data necessary to desribe the three-class situation is obtained by reinterpreting the existing data on the four types of Logistic Interdiction (LGINTDIC) cards and requiring a specific arrangement of the Unit Specification (UNITSPEC) cards for the pipeline and reserve units. The major change in the LGINTDIC cards is to substitute the transportation capacity and regeneration rates of the three logistic classes for the previous specification of regeneration rate and effective time data on the LGINTDIC Card 3. Minor changes also occur on the LGINTDIC Card 1.

The UNITSPEC cards for the three pipeline and reserve units are now required to be in consecutive order in the input where, before, logistic UNITSPEC cards had no constraints as to deck order. Several variables on the UNITSPEC card for the reserve unit are now reinterpreted to provide parameter data for the new transfer function formulations.

IV SUPPLY DISTRIBUTION MODULE

A. General

A SUPPLY DISTRIBUTION MODULE was developed as a separate adjunct to BALFRAM. This module addresses the problem of transporting supplies to a theater area. BALFRAM can first be used to establish the requirements imposed on the pipelines providing supplies to the theater area. The SUPPLY DISTRIBUTION MODULE can then be used to determine the pipeline characteristics necessary to meet these requirements.

The SUPPLY DISTRIBUTION MODULE is a computer program, designated by the acronym PIPLIN, developed under this study effort. This program considers a set of three quasi-independent supply pipelines, each pipeline representing the flow of one of three classes of supplies (bulk POL, ammunition, or other supplies) from a supply source or depot to a remote intermediate supply point (ISP) that services a set of user elements. An ISP could represent a foreign port, a remotely located supply base, a seaborne mobile logistic force, one or more AOEs in company with a task group, or simply an unattended task group taken as a whole. The user elements could represent foreign-based troops drawing supplies from a foreign port or supply base, a debarked marine force drawing supplies from a sea-based logistic support group, or a task group drawing supplies from underway replenishment ships.

Users are continuously supplied by their ISP, while the ISP is resupplied on a periodic basis by cargo carriers (ships or aircraft) whose cycle time includes transit time, loading and unloading times, preparation time, and a delay time for routine maintenance and other activity between cruises or flights. User inputs include an initial demand rate, a maximum supply level, a

safety supply level, a critical supply level (just enough supplies to enable the user to withdraw and return to a safe haven), and an essentiality priority of the user in relation to other users on the same pipeline.

Initially, the users are assumed to be stocked to their maximum supply levels, and an initial pipeline operation is set up so that the ISP can meet all the demands of its associated users. ISP inputs include a maximum storage capacity, an emergency supply level, a critical supply level, and its own supply demand rate. The initial pipeline operation dispatches cargo carriers on a periodic basis such that a cargo carrier arrives and transfers supplies to the ISP just at the time when the ISP's supply level drops to the emergency level. Thus, under the initial conditions, user demands are being met, their supply levels remain at their maximum supply levels, and the ISP does not have to draw from its emergency supplies. This pipeline operation continues until a contingency occurs, where a contingency reflects a change in a user demand rate. At this time, the pipeline operation is modified so that the ISP will be capable of meeting the new demand once the new pipeline operation is in effect. In the interim period, several things could occur. If the contingency is an increase in demand, then the ISP may have to begin drawing from its emergency supplies at some time. During this interim period, cargo carrier arrivals will be more frequent, since expected shortfalls will have to be recovered. If, during this period, the ISP has to draw from emergency supplies and cannot satisfy the user's demands (i.e., its supply level would reach the critical supply level before the arrival of the next cargo carrier), then the user supply rates are decreased in a way that takes into account their essentiality priority numbers. In this case, user supply levels will decrease, and one or more may drop below their safety levels. If this occurs, the affected user's essentiality priority will be assumed at unity, and supply rates will be readjusted. Also a user supply level may eventually reach the critical level, and, in that case, the

user is assumed to withdraw. Because the ISP will no longer have to supply that user, it can increase the supply rates of the remaining users. Also, this decrease in total demand will impose a requirement to modify the planned pipeline operation, which has not yet even stabilized. Furthermore, user withdrawal due to depletion of one class of supplies will also affect the pipelines that serviced that user for the other classes of supplies. This represents the only dependency between the three pipelines.

The pipeline operation continues in the above manner until one of four events occurs: an input-specified duration time has been reached; all users have withdrawn; an ISP's supply level will drop below its critical level before the arrival of the next cargo carrier; or all contingencies have been processed, and each pipeline operation has reached stabilization.

The output of the module consists of four tables for each pipeline. The first table specifies the times and reasons for the occurrence of selected events, such as when a user supply level drops below its safety level, a user withdraws, a cargo carrier arrives at an ISP, and so on. The second table specifies the supply levels of the ISP and the users at the time of occurrence of an event and at predetermined time intervals. The third table just prints out the supply levels at the predetermined time intervals. The fourth table prints out the supply rates of the ISP and users at the beginning of the operation and at each time that at least one of these supply rates changes value. This latter table will provide the required inputs to BALFRAM, where one or more of the users could represent supply nodes within the BALFRAM scenario.

A detailed description of the SUPPLY DISTRIBUTION MODULE is presented in the next section of this chapter. A sample problem that illustrates the use of the module is discussed in Section C. In Section D, the limitations of the module are discussed, indicating feasible areas for future improvements.

B. Module Description

The SUPPLY DISTRIBUTION MODULE consists of the main program (PIPLIN) and four subroutines (REVISE, NEXTEV, ALLOC, and SHTFAL). Figures IV-1 to IV-10 present logic flowcharts of program PIPLIN and Figures IV-11 to IV-14 present logic flowcharts for the respective subroutines. The appendix to this report provides an alphabetical listing of all the module nomenclature and a complete listing of the module computer program.

The module can essentially be broken down into 14 functional processing sections: Initialization, Control, Cargo Carrier Arrival Processing, ISP Emergency Supply Level Processing, User Safety Level Processing, User Withdrawal Processing, Contingency Event Processing, Routine Printout Processing, Scheduled Run Termination Processing, Output Processing, Subroutine REVISE, Subroutine NEXTEV, Subroutine ALLOC, and Subroutine SHTFAL. In the description of the module that follows, each of these processing sections is discussed in turn.

The basic time units used in the modules are in terms of days. Thus, the rates assumed are daily rates. The general indexing convention used in the module description is as follows:

P = a pipeline number (P = 1,2, or 3)

I = user number (I = 2, ... , NB where NB denotes the number of users, a program input)

J = cargo carrier number (J = 1..., NTC(P) where NTC(P) denotes the number of cargo carriers presently assigned to pipeline P, a program variable)

NCO = contingency event number (NCO = 1, ..., NOC where NOC is the number of planned contingencies, a program input)

In some cases, the index I may assume values NB1 = NB + 1, NB2 = NB + 2, and NB3 = NB + 3, which respectively refer to the ISP, a contingency, and a scheduled printout or run termination.

1. <u>Initialization (Fig. IV-1)</u>

The module is initiated by reading in a set of inputs for a given problem. Table IV-1 presents a summary listing of the input data. The detailed program inputs, including format descriptions, are specified in the appendix. At this time, the output table headings are printed out. There is a total of twelve output tables generated by the module, four for each pipeline. For a given pipeline, the first table represents an "Event Chronology" (the possible event types are described later in this section). Anytime an event occurs that affects the given pipeline, the table indicates the time of occurrence, the event type number, and the event description. Scheduled printout events are not included, because they have no effect on the pipeline operation. The second table portrays "Event Sequenced Supply Levels." Anytime an event occurs, including scheduled printout events, the supply levels for the ISP and each user are tabulated. For Cargo Carrier Arrival Events, supply levels are tabulated at both the time of arrival and time of departure of the cargo carrier, neglecting the cargo unloading time. The third table portrays "Time Sequenced Supply Levels." This simply tabulates the ISP and user supply levels at the scheduled printout times. The fourth table portrays "Supply Rate Variations." Whenever the supply rate changes, the time of change, the event type number instigating the change, and the supply rates for the ISPS and each user are tabulated. These Supply Rate Variation tables provide the link between this module and the main BALFRAM.

The next step is to establish the static pipeline flow parameters for each pipeline. This initial pipeline operation is set up so that the ISP can meet all the demands of the users and not have to draw from its emergency supplies. For a given pipeline, the procedure for accomplishing this is as follows. First, the total demand rate on the ISP, denoted by MD(P), is determined by summing up the individual user demand rates specified by input as BIR(I,P), including the ISP's own demand

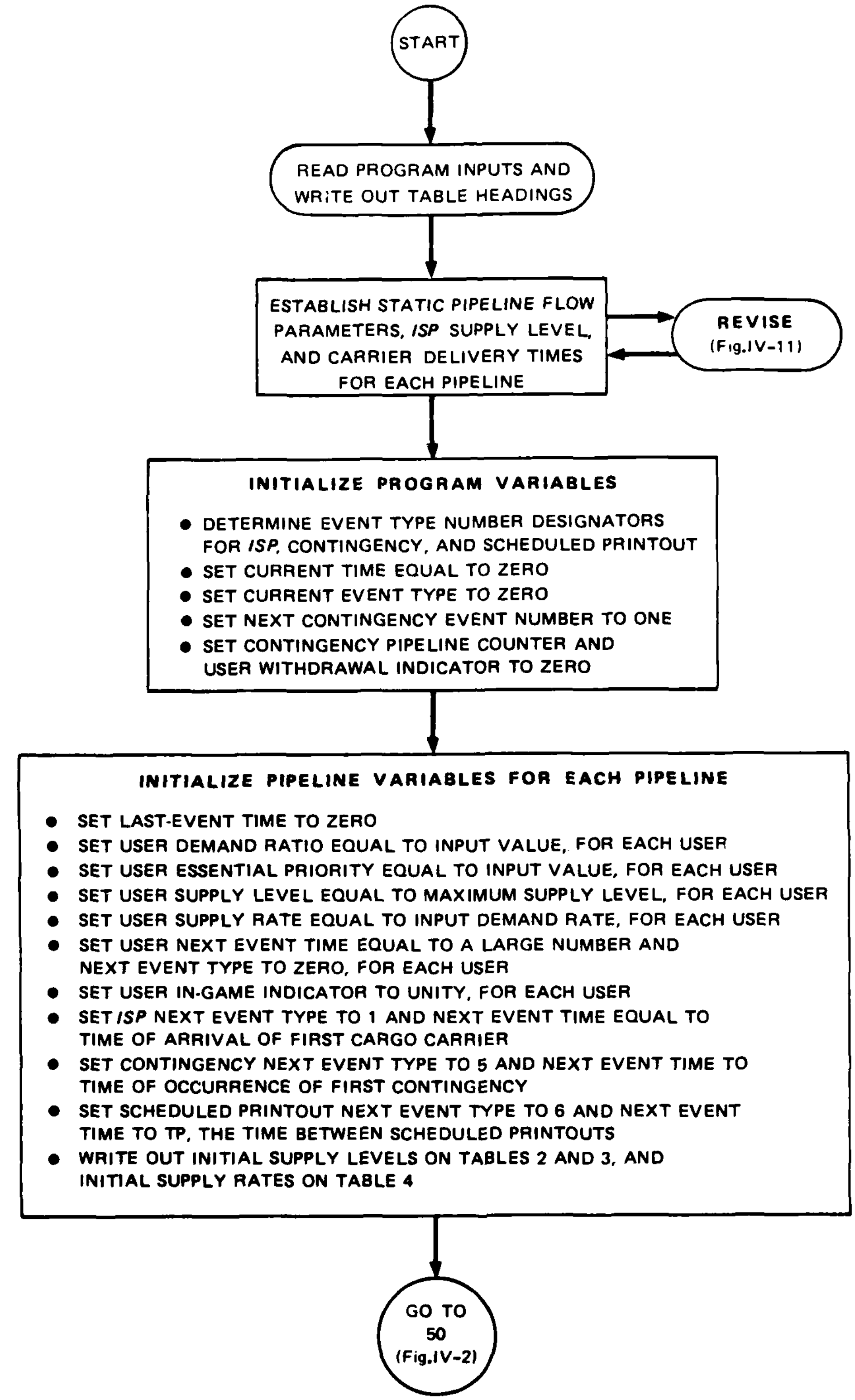

FIGURE IV-1. LOGIC FLOWCHART (INITIALIZATION)

Table IV-1

MODULE INPUTS

Descriptor	Variable Name
<u>Scheduled Printout Inputs</u>	
Printout interval (days)	TP
Scheduled run duration (days)	TDUR
<u>Supply Source Inputs per Pipeline</u>	
Pipeline name	PN(P)
Cargo carrier capacity (ST or kbbl)	SCC(P)
Cargo carrier speed (knots)	SCS(P)
Cargo carrier loading rate (ST/day or kbbl/day)	SCL(P)
Cargo preparation rate (ST/day or kbbl/day)	SPR(P)
Recycle down time (days)	SDT(P)
<u>ISP Inputs per Pipeline</u>	
Storage capacity (ST or kbbl)	MSC(P)
Cargo carrier unloading rate (ST/day or kbbl/day)	MSU(P)
Own supply demand rate (ST/day or kbbl/day)	MDR(P)
Emergency stores level (ST or kbbl)	MES(P)
Critical stores level (ST or kbbl)	MCS(P)
Transit distance between supply source and ISP (nmi)	MSD(P)
Order time (days)	MOT(P)
<u>User Inputs per Pipeline</u>	
Number of users (same for each pipeline)	NB
User I-initial demand rate (ST/day or kbbl/day)	BIR(I,P)
User I-initial essentiality priority number	BIP(I,P)
User I-maximum supply level (ST or kbbl)	BML(I,P)
User I-safety supply level (ST or kbbl)	BSL(I,P)
User I-critical supply level (ST or kbbl)	BCL(I,P)
<u>Contingency Inputs</u>	
Number of contingencies	NOC
User number associated with NCOth contingency	CUN(NCO)
Time at which NCOth contingency occurs (days)	TC(NCO)
User demand rate for pipeline P after occurrence of NCOth contingency (ST/day or kbbl/day)	CUD(NCO,P)
User essentiality priority number for pipeline P after occurrence of NCOth contingency	CUP(NCO,P)

ST - Short Tons
kbbl - Thousands of Barrels

rate MDR(P). Thus,

$$MD(P) = MDR(P) + \sum_{I=1}^{NB} BIR(P) \qquad \text{(IV-1)}$$

Since initially all demands will be satisfied, the ISP supply rate SR(P) is set equal to the demand rate. Thus,

$$SR(P) = MD(P) \qquad \text{(IV-2)}$$

For subsequent use, the user demand rate MDP(P) and supply rate SRP(P) are required. These are given as follows:

$$MDP(P) = MD(P) - MDR(P) \qquad \text{(IV-3)}$$

$$SRP(P) = SR(P) - MDR(P) \qquad \text{(IV-4)}$$

The module next establishes the required cycle time for a cargo carrier with a full load. This includes the round trip transit time between the supply source and the ISP, the cargo preparation-for-shipment time, the cargo carrier loading and unloading times at the supply source and ISP respectively, and the recycle down time for the cargo carrier. This latter factor includes sufficient time for cargo carrier maintenance, liberty for the crew, and other activities required between cruises.

This cycle time, denoted by TCY(P), is computed as follows:

$$TCY(P)=SCC(P) \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)}\right) + \frac{2 \bullet MSD(P)}{24 \bullet SCS(P)} + SDT(P) \qquad (IV-5)$$

where SCC(P) = cargo carrier capacity

SPR(P) = cargo preparation rate

SCL(P) = cargo loading rate at the supply source

MSU(P) = cargo unloading rate at the ISP

MSD(P) = transit distance between supply source and ISP

SCS(P) = cargo carrier speed

SDT(P) = recycle down time.

The above parameters are all program inputs. The module then calls on subroutine REVISE to determine the necessary pipeline flow parameters. These computations are described later in Section 11, Subroutine REVISE. The principal outputs of this subroutine are: NC(P), the number of cargo carriers required to maintain the pipeline operation; CL(P), the cargo carrier load which may, in some cases, be less than its full capacity; and TR(P), the separation time between cargo carriers (that is, the time between arrival of cargo carriers at the ISP). At this juncture, it is assumed that a cargo carrier has just departed from the ISP so that the ISP supply level SL(P) is at the maximum storage capacity. That is,

$$SL(P) = MSC(P) \qquad (IV-6)$$

here MSC(P) is the input-specified ISP storage capacity. Also, an indicator variable ESP(P) is set equal to zero to signify that the ISP is not drawing from its emergency supplies.

The next function performed by the module is to schedule the arrival of all the cargo carriers assigned to the pipeline. For computational purposes, it is actually required to schedule the arrival of one additional cargo carrier (that is, to schedule the second arrival of the first scheduled cargo carrier). The variable NTC(P) = NC(P) + 1 denotes the number of scheduled arrivals maintained in module storage. Associated with each cargo carrier arrival time, denoted by DT(J,P), is also the cargo carrier load, denoted by DC(J,P). At the onset, these variables are given by the following equations, where J ranges from 1 to NTC(P):

$$DT(J,P) = J \cdot TR(P) \tag{IV-7}$$

$$DC(J,P) = CL(P) \tag{IV-8}$$

where TR(P) and CL(P) were computed in subroutine REVISE, as indicated above.

The remainder of this portion of the module is concerned with the initializing of the remaining program and pipeline operating variables. The module is an event-sequenced model. That is, the time variable is incremented by the occurrence of an event. Thus, module computations are performed only at the time of occurrence of specific events. The variable ET denotes an event type. The seven event types included in the

module are as shown in the following table.

ET	Event Type
1	Cargo carrier arrival
2	ISP begins drawing from emergency supplies
3	User's supply level drops down to safety level
4	User's supply level reaches critical level (user withdraws)
5	Contingency occurs
6	Scheduled printout
7	Scheduled run termination

The array SE(I,P) denotes the next type of event associated with user I, relative to pipeline P, and the array TE(I,P) stores the time of occurrence of this event. Initially SE(I,P) is set equal to zero for each I, which indicates that there is no next event associated with the user, and TE(I,P) is set equal to a very large number (1×10^9). It should be noted here that, for users, only Event Types 3 and 4 are applicable, that is, SE(I,P) can only assume the event type values of 3 or 4, in addition to the no event value of zero. Although a contingency event (ET = 5) is user-dependent, it is treated as a special case. These arrays also contain three additional elements. The first represents an ISP-related event and has an index value of NB1 = NB+1, where NB is the number of users. At the onset, the next ISP related event will be the arrival of the first cargo carrier. Thus, SE(NB1,P) is set equal to 1, and TE(NB1,P) is set equal to the scheduled arrival time of the first cargo carrier, DT(1,P). Note here that SE(NB1,P) can only assume the values of 1 or 2, the arrival of a cargo carrier or the ISP beginning to draw from its emergency supplies. The second additional element represents a contingency

event and has an index value of NB2 = NB+2. The event type for this element is always a contingency event, so that SE(NB2,P) = 5 at all times. Initially the time of occurrence of the next contingency event is set equal to the time of occurrence of the first contingency as specified by input. That is, TE(NB2,P) = TC(1). The contingency event counter NCO is also set equal to one. The third additional element represents a scheduled run control operation and has an index value NB3 = NB + 3. Event Types 6 and 7 are associated with SE(NB3,P), and initially SE(NB3,P) = 6, with TE(NB3,P) = TP, the scheduled printout interval.

There are several other program variables initialized at this point. The current time variable CT is set equal to 0.0, and the current event variable ET is set equal to zero, which indicates that this is the start of the run. A contingency pipeline counter IC is set equal to zero, as is also a user withdrawal indicator IW. IC is used in the processing of contingency events (Section 7), and IW is used in the processing of user withdrawal events (Section 6). Descriptions of their use are deferred until the processing of the respective events are discussed.

The additional pipeline variables to be initialized are user-oriented, with the exception of the last event time TLE(P), which is set equal to 0.0. The user variables to be initialized are the user demand rate BR(I,P), the user essential priority (in relation to other users) BP(I,P), the user supply level BL(I,P), the user supply rate BS(I,P), and a user in-game ilndicator BIG(I). The latter is initially set equal to one to indicate that the user is active. Should a user eventually withdraw, this indicator would then be set equal to zero. The other user variables are set equal to their respective input-specified values. Thus,

$$BR(I,P) = BIR(I,P) \tag{IV-9}$$

$$BP(I,P) = BIP(I,P) \tag{IV-10}$$

$$BL(I,P) = BML(I,P) \tag{IV-11}$$

$$BS(I,P) = BIR(I,P) \tag{IV-12}$$

The latter equation holds true because, at the onset, user demands are being satisfied.

The final operations performed under the initialization function are to print out the supply levels and supply rates at time zero on Output Tables 2,3, and 4 for each pipeline.

The module is now ready to begin the actual pipeline operations, and proceeds to the control function.

2. Control (Fig. IV-2)

As mentioned before, the module is an event-sequencing type. That is, the time variable increases in accordance with the time of the next event. The control function simply establishes the time and character of the next event to be processed. The arrays TE(I,P) contain the time of the next event for each user and also for the ISP, contingencies, and scheduled run control operations for each pipeline. The associated array SE(I,P) identifies the type of event to be processed. At the completion of processing an event, the module will first set the last-event time for the associated pipeline TLE(P) equal to the current time. It then scans the TE(I,P) arrays to determine the time of the next event and sets the current time equal to this next event time. Thus,

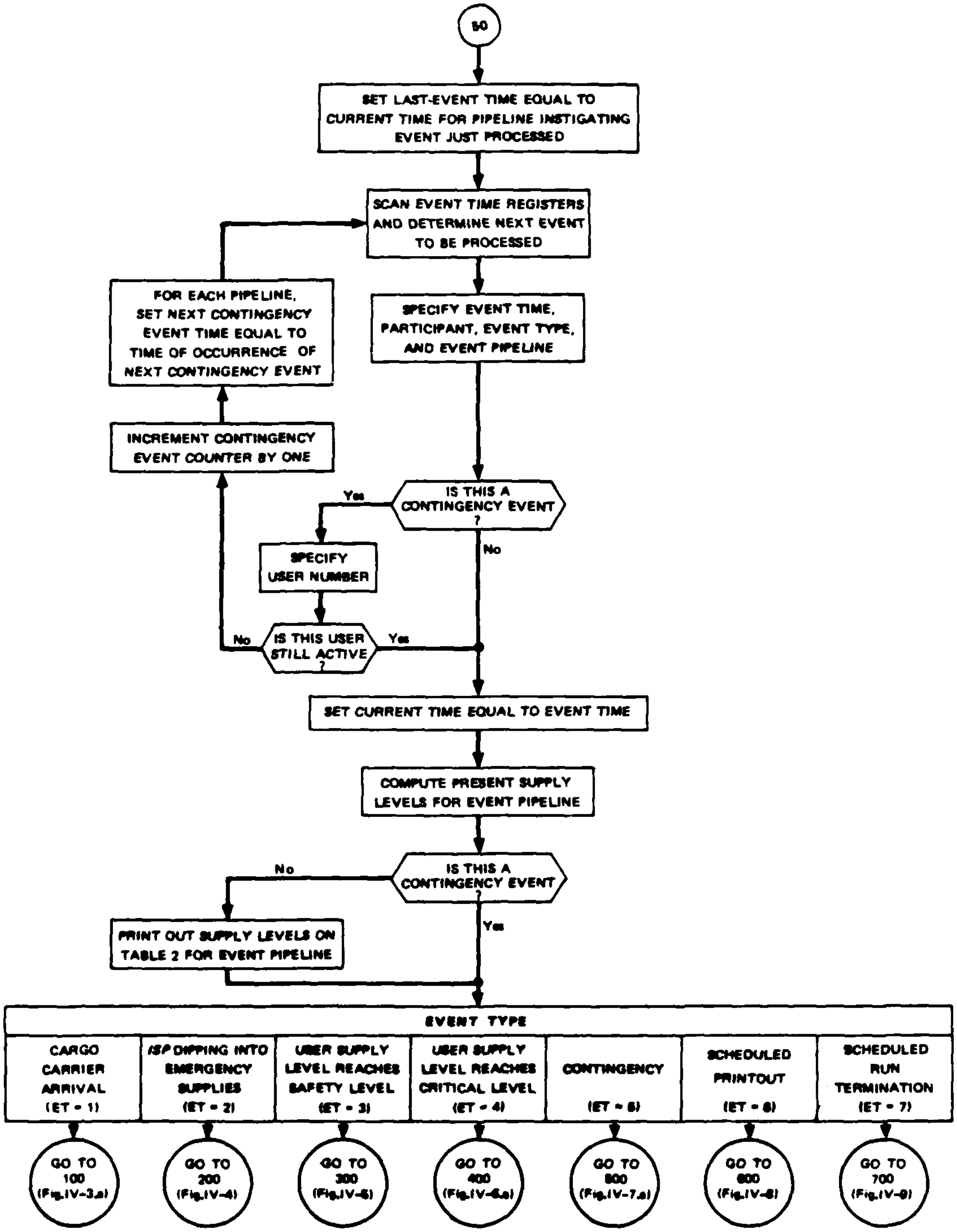

FIGURE IV-2. LOGIC FLOWCHART (CONTROL)

$$CT = \min_{(I=1...,NB3;P=1,2,3)} \left\{ TE(I,P) \right\} \qquad (IV-13)$$

The value of P such that TE(I,P) achieves this minimum identifies the pipeline associated with the event and the associated value of I identifies the user if I = NB, or identifies the event as an ISP-dependent event (I = NB1), a contingency event (I = NB2), or a scheduled run control event (I = NB3). The variables JP and JE are set equal to the particular values of P and I, respectively, generating the event. Thus, SE(JE,JP) identifies the type of event to be processed, so that the event type variable ET is set equal to SE(JE,JP).

If the event to be processed is a contingency event (ET = 5), the variable JT is set equal to the user number instigating the event, that is JT = CUN(NCO). If this user is no longer active (BIG(JT) = 0), then this event will not occur, and the contingency event counter NCO is incremented by one. Also, for each pipeline, the next contingency event time TE(NB2,P) is set equal to the time of occurrence of the next contingency. That is, TE(NB2,P) = TC(NCO) for each P. In this case, the module then again scans the TE(I,P) arrays to determine the time of the next event and repeats the procedure described above. Otherwise, the module sets the current time equal to the event-occurrence time (CT = TE(JE,JP)) and computes the present supply levels for the pipeline, inducing the event according to the following equation

$$BL(I,P) = BL(I,P) - (BR(I,P) - BS(I,P)) \bullet (CT-TLE(P)) \qquad (IV-14)$$

$$SL(P) = SL(P) - SR(P) \bullet (CT-TLE(P)) \qquad (IV-15)$$

If this event is not a contingency, then the module prints out

these new supply levels on Table 2 for the pipeline associated with this event (for a contingency event, each pipeline may or may not be affected, so the supply level printouts are deferred until the event is actually processed). The module then proceeds to process the event identified by ET in accordance with the associated event processing described in the next seven sections.

3. Cargo Carrier Arrival Processing (Fig. IV-3)

On the arrival of a cargo carrier at an ISP, the ISP supply level is increased by the amount of the cargo carrier load. That is

$$SL(P) = SL(P) + DC(1,P) \qquad (IV\text{-}16)$$

Where P denotes the pipeline that is affected by this cargo carrier arrival. That is, P + JP, where JP identified the pipeline associated with this event previously in the control processing. The module then prints out the message "CARGO CARRIER ARRIVAL AT ISP" on the Event Chronology (Table 2) for this pipeline. For subsequent computations, the previous pipeline supply rate SROLD is stored, where

$$SROLD = SR(P) \qquad (IV\text{-}17)$$

Also, a pipeline stabilization indicator ITERM(P) is set equal to zero, which will later signify that the pipeline operation has not reached stabilization. The module then checks to see if there are any interim cargo carriers in the pipeline operation. The variable NIC(P) denotes the number of such cargo carriers. Interim cargo carriers in the pipeline arise when there is a change in the static pipeline operation, which can occur when there is a contingency event or when a user withdraws.

If there are no interim carriers in this pipeline (NIC(P) = 0), then the pipeline is in a stabilized state, and the

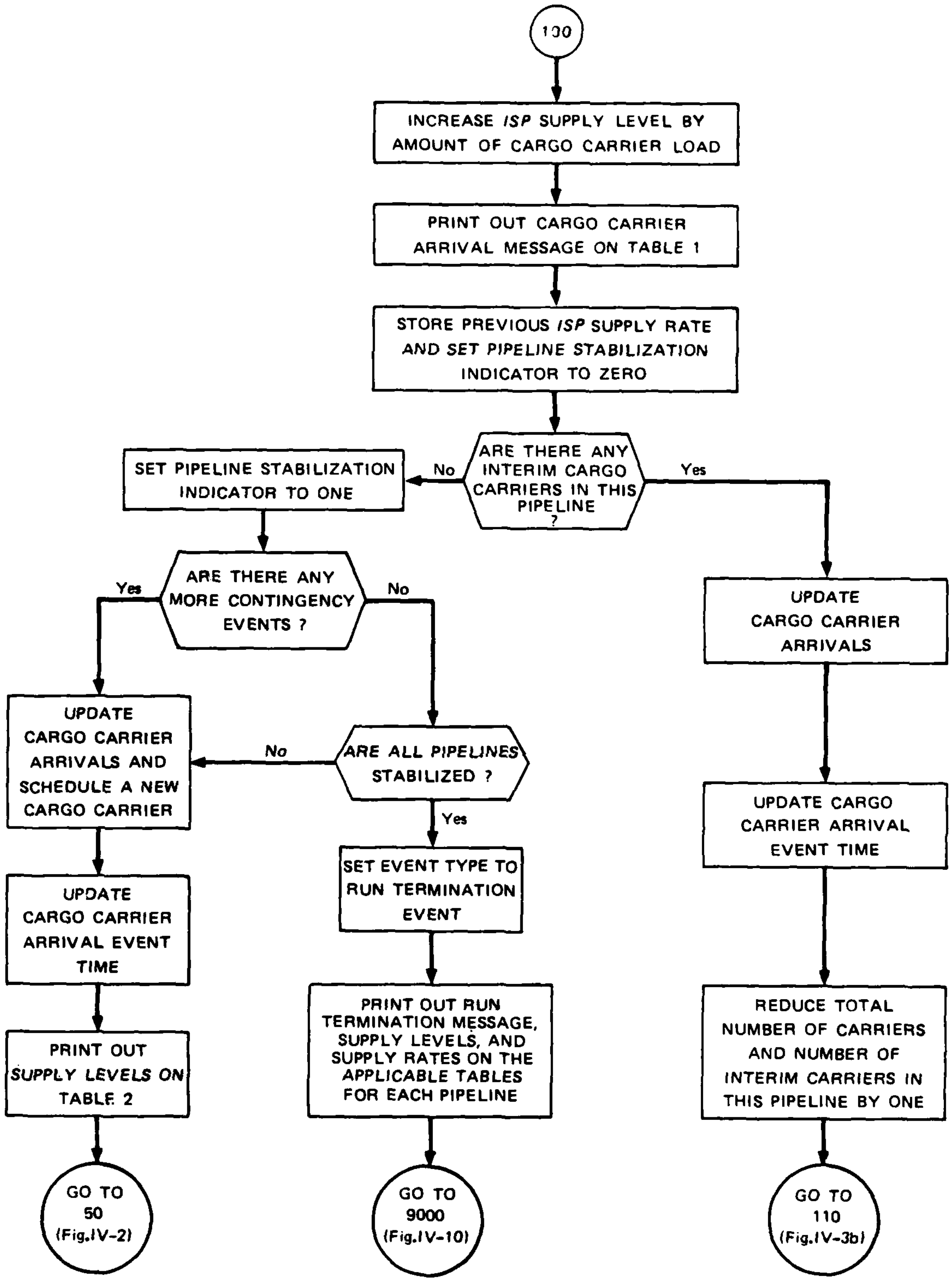

FIGURE IV-3.a LOGIC FLOWCHART (CARGO CARRIER ARRIVAL PROCESSING)

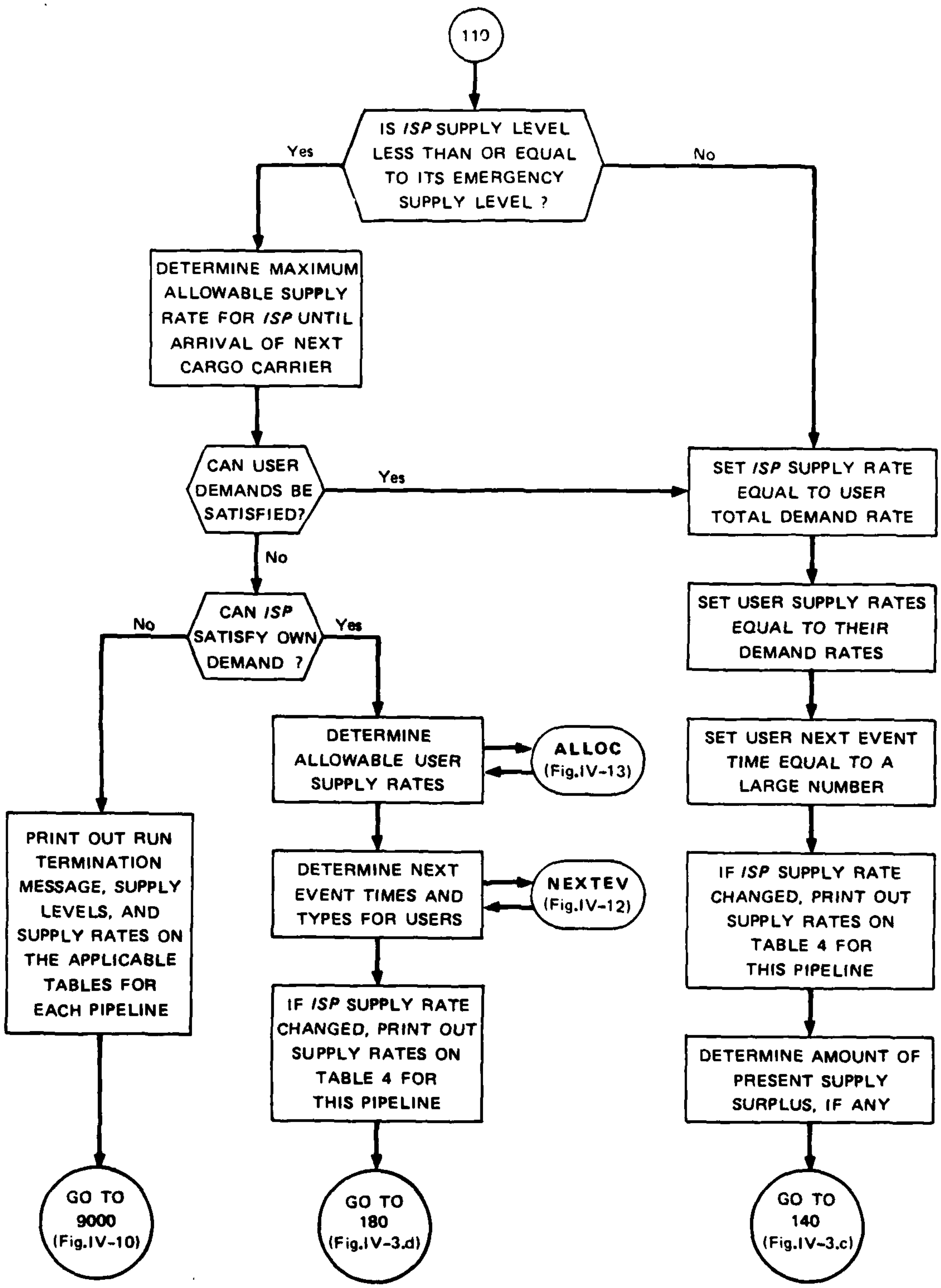

FIGURE IV-3.b LOGIC FLOWCHART (CARGO CARRIER ARRIVAL PROCESSING)

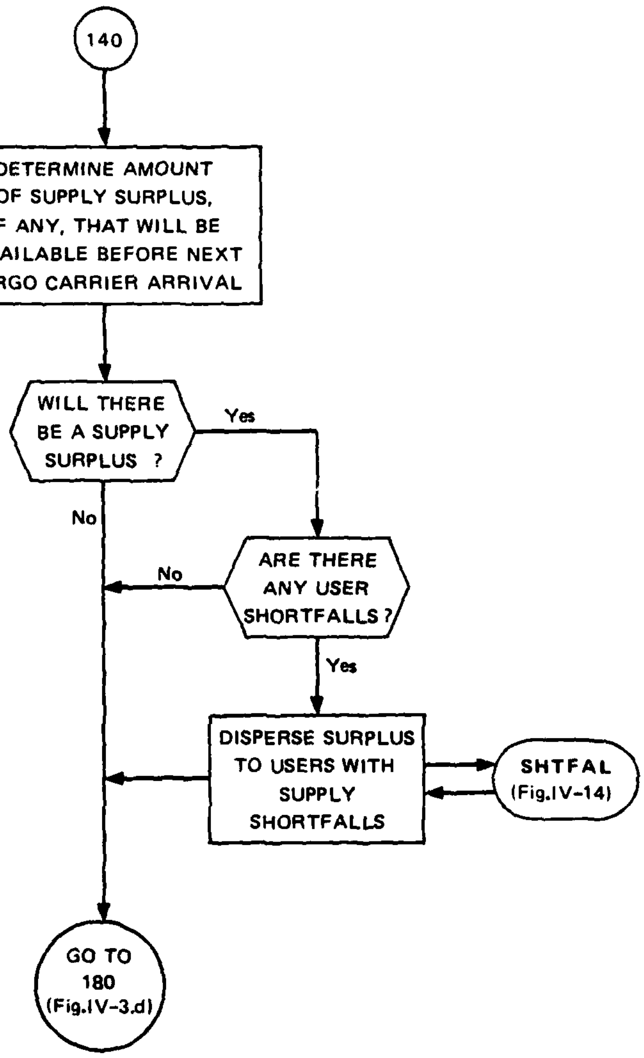

FIGURE IV-3.c LOGIC FLOWCHART (CARGO CARRIER ARRIVAL PROCESSING)

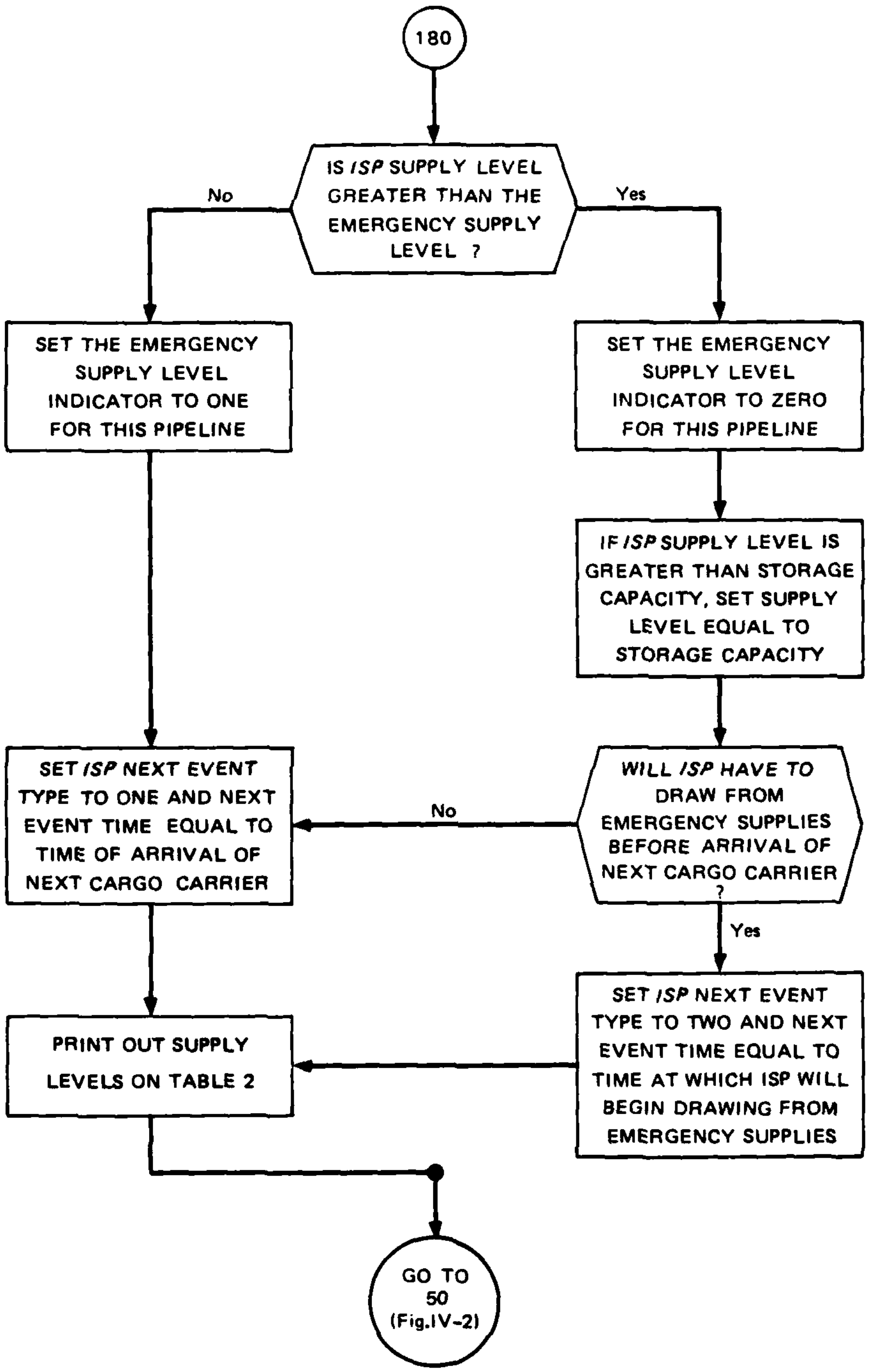

FIGURE IV-3.d LOGIC FLOWCHART (CARGO CARRIER ARRIVAL PROCESSING)

stabilization indicator ITERM(P) is set equal to one. If there are no more contingency events to be processed (NCO > NOC), and all three pipeline operations have reached stabilization (ITERM(P) = 2 for each pipeline), the computer run will be terminated. In this case, the event type ET will be set equal to seven (run termination), and the message "RUN TERMINATED--LAST CONTINGENCY HAS BEEN STABILIZED" will be printed out on the Event Sequenced Supply Level table (Table 2) and the Time Sequenced Supply Level table (Table 3) for each pipeline, and the supply rates will be printed out on the Supply Rate Variation table (Table 4) for each pipeline. The module then proceeds to Output Processing (Section 10). If there is another contingency to be processed, or if at least one pipeline operation has not reached stabilization, then the module will continue running. In this case, cargo carrier arrivals are updated, and a new cargo carrier is scheduled for the pipeline operation. This accomplished as follows, where J ranges from 2 to NTC(P):

$$DT(J-1,P) = DT(J,P) \tag{IV-18}$$

$$DC(J-1,P) = DC(J,P) \tag{IV-19}$$

$$DT(NTC(P),P) = DT(NTC(P)-1,P)+TR(P) \tag{IV-20}$$

$$DC(NTC(P),P) = DC(NTC(P)-1,P) \tag{IV-21}$$

The next cargo carrier arrival event time TE(NB1,P) is also updated by setting it equal to the new value of DT(1,P). At this point, the module prints out the supply levels on the Event Sequenced Supply Level table for this pipeline and returns to Control (Section 2).

If there are interim carriers in the present pipeline, then the processing of this event follows another course. First, the cargo carrier arrivals are updated in accordance with Eq.

(IV-17) and (IV-18) above. Because the present arriving cargo carrier is an interim carrier, the number of interim cargo carriers NIC(P) and the total number of cargo carriers in the pipeline NTC(P) are each decreased by one. No new cargo carriers are scheduled, because the pipeline operation has not yet stabilized. The next cargo carrier arrival event time TE(NB1,P) is also updated by setting it equal to the time of arrival of the next cargo carrier, the new value of DT(1,P). A test is then made to determine if the ISP supply level is greater than its emergency supply level.

If the ISP supply level is greater than its emergency supply level (SL(P) > MES(P)), then the ISP can (for the present, anyway) satisfy all demands. In this case, the ISP supply rate SR(P) is set equal to the total demand rate MD(P), each active user's supply rate BS(I,P) is set equal to its demand rate BR(I,P), and the user's next event time TE(I,P) is set equal to a large number. If the ISP's new supply rate is different than before (SR(P) ≠ SROLD), then the supply rates are printed out on the Supply Rate Variation table for this pipeline. At this point, it may be that the cargo carrier's load was greater than the ISP could handle. This excess is called the present supply surplus SFM1. It can be distributed immediately to any users with supply shortfalls, as will be described later. Thus,

$$\text{SFM1} = \begin{cases} 0. & \text{if SL(P)} \leq \text{MSC(P)} \\ \text{SL(P)-MSC(P)} & \text{if SL(P)} > \text{MSC(P)} \end{cases} \qquad \text{(IV-22)}$$

The next step is to determine the amount of future supply surplus SFM2 that may be available before the next cargo carrier arrival.

This is determined by the following equation

$$SFM2 = \max \left\{ 0.,\ SL(P)-SR(P) \bullet (DT(1,P)-CT)-MCS(P) \right\} \qquad \text{(IV-23)}$$

The total amount of supply surplus SFM that can be distributed at this time is given by:

$$SFM = SFM1 + SFM2 \qquad \text{(IV-24)}$$

If SFM is greater than zero and there are users with supply shortfalls, then this supply surplus is distributed to users in accordance with the procedures described in Subroutine SHTFAL (Section 14). Otherwise the cargo carrier will return to its home base with an amount of supplies equal to SFM1. Because the ISP supply level is greater than its emergency supply level, its emergency supply level indicator ESP(P) is set equal to zero to signify that the ISP is not drawing from emergency supplies. If the present indicated ISP supply level SL(P) is greater than its maximum storage capacity MSC(P), then SL(P) is now set equal to MSC(P). The next step is to determine if the ISP will have to draw from its emergency supplies before the arrival of the next cargo carrier. This is accomplished by first determining the time TEM at which the ISP would begin drawing from its emergency supplies under the present ISP supply rate, assuming no cargo carrier arrives before then. This is given by

$$TEM = CT + \frac{SL(P) - MES(P)}{SR(P)} \qquad \text{(IV-25)}$$

If TEM = DT(1,P), then a cargo carrier will arrive before this

occurs, and the ISP's next event type will be a cargo carrier arrival, so that SE(NB1,P) = 1 and TE(NB1,P) = DT(1,P). Otherwise, the ISP's next event type will be its beginning to draw from emergency supplies, so SE(NB1,P) = 2 and TE(NB1,P) = TEM. At this point, the module prints out the supply levels on the Event Sequenced Supply Level table for this pipeline and returns to Control (Section 2) to determine the next event to be processed.

If the ISP supply level is not greater than its emergency supply level (SL(P) $\leq$ MES(P)), then the ISP may or may not be able to satisfy all user demands. Thus, the maximum allowable supply rate SRT for this pipeline is computed as follows

$$SRT = \frac{SL(P) - MCS(P)}{DT(1,P)-CT} \qquad (IV\text{-}26)$$

At this supply rate, the ISP supply level would just drop to its critical level at the time of arrival of the next cargo carrier. If this maximum allowable supply rate is greater than or equal to the total demand rate (SRT $\geq$ MD(P)), then the remainder of the processing of this event is the same as in the previous case where the ISP supply level was greater than its emergency supply level, with the following exceptions: there is no present supply surplus so that SFM1=0.; the ISP emergency supply level indicator ESP(P) will remain equal to one; and the next event type for this pipeline will be a cargo carrier arrival, that is, SE(NB1,P) = 1 and TE(NB1,P) = DT(1,P). If, on the other hand, the ISP cannot satisfy all demand with its maximum allowable supply rate (SRT < MD(P)), then a check is made to determine if the ISP can satisfy its own demand (SRT $\geq$ MDR(P)). If the answer is no, then the

computer run will be terminated as the ISP would have to withdraw before the arrival of the next cargo carrier. In this case, the event type ET will be set equal to seven, and the message, "RUN TERMINATED--ISP CANNOT MAINTAIN SELF-SUPPLY, PIPELINE PN(P)" will be printed out on the Event Chronologies for each pipeline, where the PN(P) specified in the message is the pipeline name of the pipeline instigating the run termination. In addition, the supply levels will be printed out on the Event Sequenced Supply Level table and the Time Sequenced Supply Level table for each pipeline, and the supply rates will be printed out on the Supply Rate Variation table for each pipeline. The module then proceeds to Output Processing (Section 10).

If the ISP can satisfy its own demand, then the ISP supply rate SR(P) is set equal to SRT, and the allowable user supply rates are determined. Subroutine ALLOC (Section 13) determines weighting factors WB(I) that determine the amount of the expected shortfall to be allocated to each user. These weighting factors take into account the users' demand rates and essential priorities. The new user supply rates are then computer as follows:

$$BS(I,P) = BR(I,P) - WB(I) \bullet (MD(P) - SR(P)) \qquad \text{(IV-27)}$$

The next step is to call on Subroutine NEXTEV (Section 12) to determine the next event times and types for each user, relative to the pipeline being processed. If the ISP supply rate has changed from its previous value (SR(P) $\neq$ SROLD), then the new supply rates are printed out on the Supply Rate Variation tabble for this pipeline. The ISP emergency supply indicator ESP(P) for this pipeline remains at unity, and the next event will be a cargo carrier arrival, that is, SE(NB1,P) = 1 and TE(NB2,P) 1= DT(1,P). The supply levels are then printed out on the Event

Sequenced Supply Level table for this pipeline, and the module returns to Control (Section 2) to determine the next event to be processed. This completes the Cargo Carrier Arrival processing function.

4. ISP Emergency Supply Level Processing (Fig. IV-4)

When an ISP's supply level drops below its emergency supply level, the module immediately prints out the message "ISP DIPPING INTO EMERGENCY SUPPLIES" on the Event Chronology for this pipeline. It also sets the ISP's emergency supply level indicator ESP(P) equal to one. Next, the maximum allowable supply rate for the ISP, denoted by SRT, is computed in the same manner as indicated previously in Eq. (IV-26).

If user demands can still be satisfied (SRT $\geq$ MD(P)), then the next event for the ISP will be a cargo carrier arrival, that is, SE(NB2,P) = 1 and TE(NB1) = DT(1,P). The module then returns to Control (Section 2) to determine the next event to be processed.

If user demands cannot be satisfied, the ISP supply rate SR(P) is set equal to its maximum allowable supply rate, SRT, and the module checks to see if the ISP can satisfy its own demand (SRT $\geq$ MDR(P)). If the answer is no, then the computer run will be terminated, as the ISP would have to withdraw before the arrival of the next cargo carrier. In this case, the event type ET is set equal to seven, and the message 'RUN TERMINATED--ISP CANNOT MAINTAIN SELF-SUPPLY, PIPELINE PN(P)' will be printed out on the Event Chronologies for each pipeline, where the PN(P) specified in the message is the name of the pipeline instigating the run termination. In addition, the supply levels will be printed out on the Event Sequenced Supply Level table and the Time Sequenced Level table for each pipeline, and the supply rates will be printed out on the Supply Rate Variation table for each pipeline. The module then proceeds to Output Processing (Section 10).

If the ISP can satisfy its own demand, the allowable

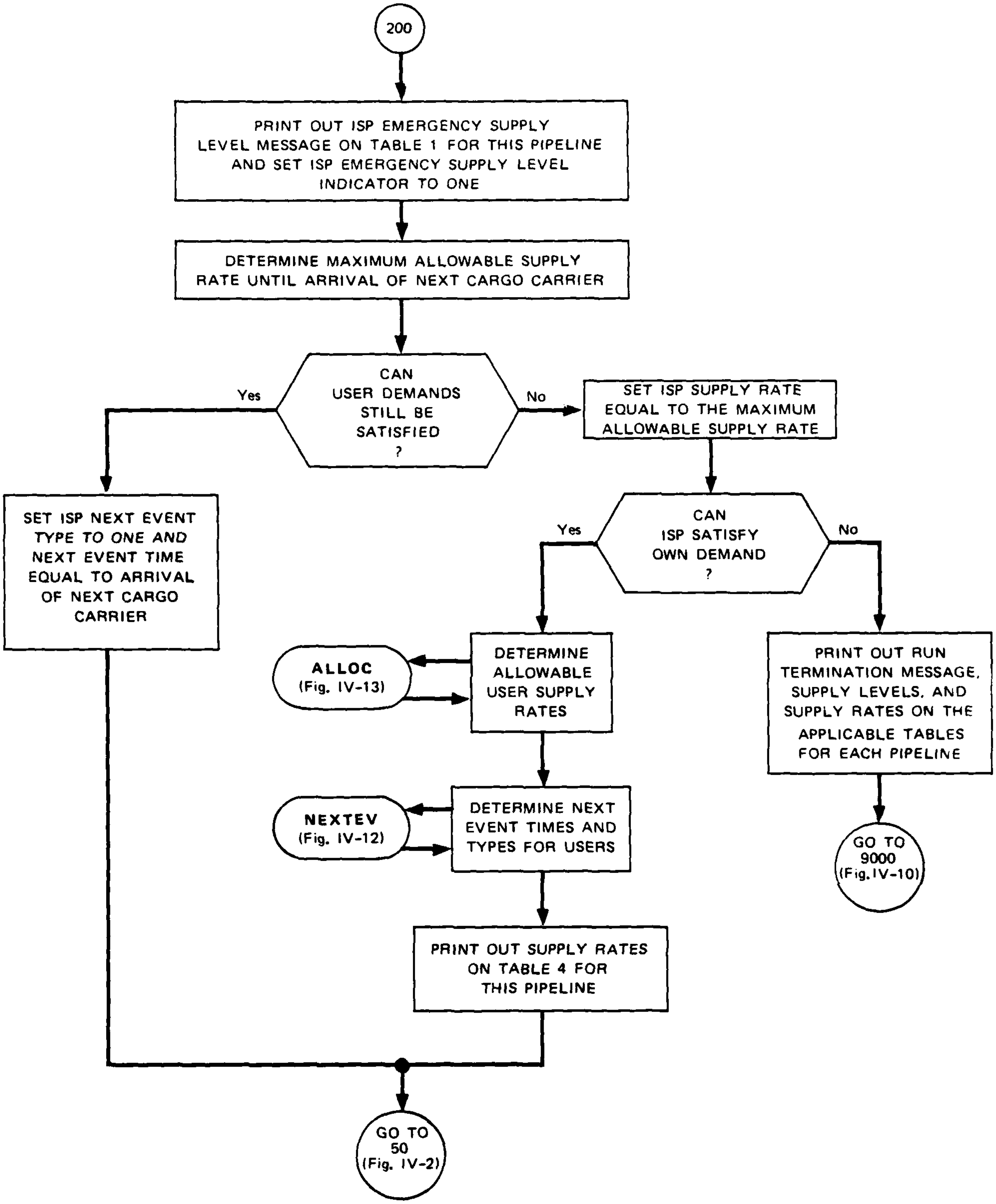

FIGURE IV-4 LOGIC FLOWCHART (ISP EMERGENCY SUPPLY LEVEL PROCESSING)

user supply rates and the next event times and types for each user relative to the pipeline being processed are determined in the same manner as that described at the end of the previous section. The new supply rates are printed out on the Supply Rate Variation table for this pipeline, and then the module returns to Control (Section 2) to determine the next event to be processed. This completes the ISP Emergency Supply Level Processing.

5. User Safety Level Processing (Fig. IV-5)

When a user's supply level drops below its safety level, the module prints out the message "SUPPLY LEVEL DROPS BELOW SAFETY LEVEL--USER NUMBER JE" on the Event Chronology for this pipeline. For subsequent use, the user's previous supply rate BSOLD is stored, where

$$BSOLD = BS(JE,P) \qquad (IV-28)$$

with JE denoting the index of the user instigating this event. The user's essential priority BP(JE,P) is set equal to four. The module next determines new supply rates for each user in this pipeline and then establishes the next event types and times of each user relative to the pipeline being processed. These are done in the same manner as that described at the end of Section 3 (Cargo Carrier Processing). If the supply rates change, the new supply rates are printed out on the Supply Rate Variation table for this pipeline, and then the module returns to Control (Section 2) to determine the next event to be processed. This completes the User Safety Level processing.

6. User Withdrawal Processing (Fig. IV-6)

When a user's supply level reaches its critical level, the user has just enough supplies furnished by the event-instigating pipeline to withdraw from its assigned station

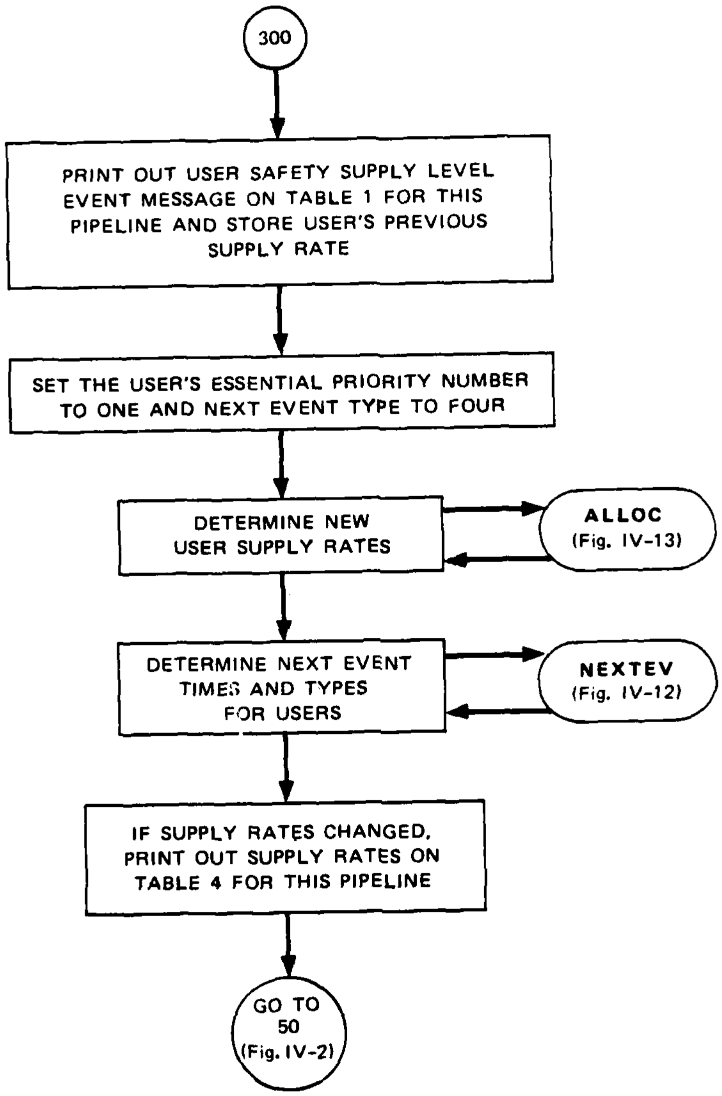

FIGURE IV-5 LOGIC FLOWCHART (USER SAFETY LEVEL PROCESSING)

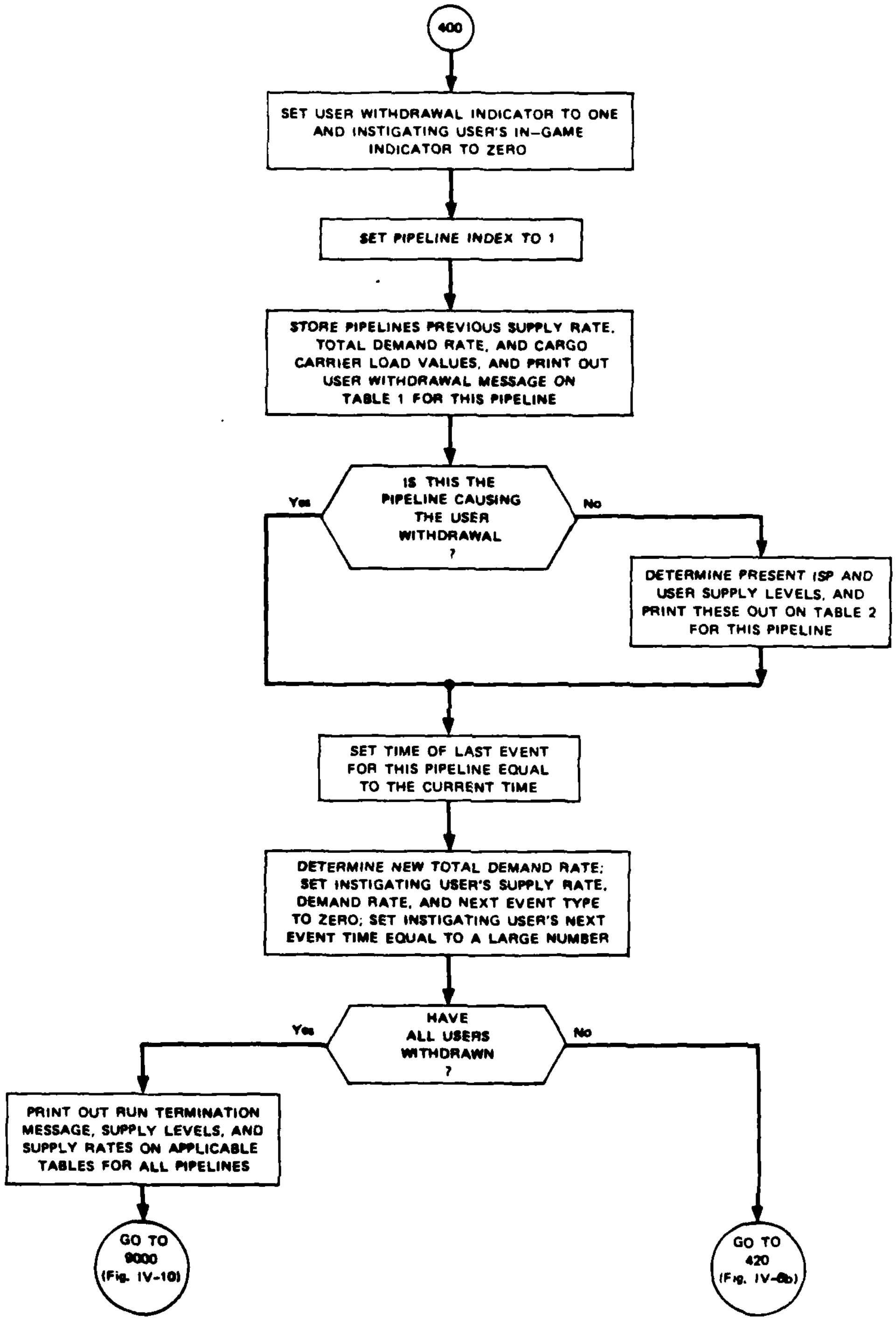

FIGURE IV–6a LOGIC FLOWCHART (USER WITHDRAWAL PROCESSING)

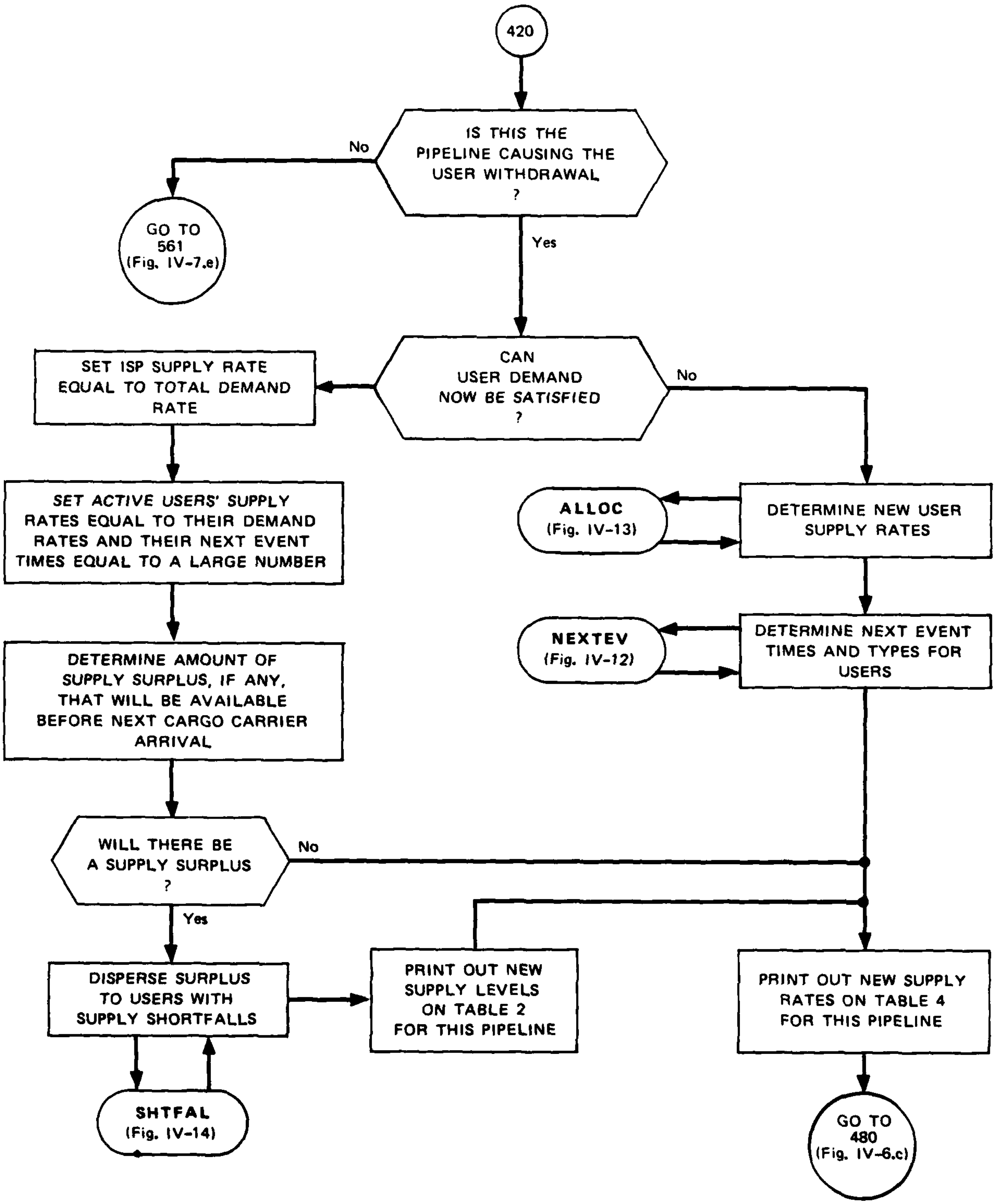

FIGURE IV-6.b LOGIC FLOWCHART (USER WITHDRAWAL PROCESSING)

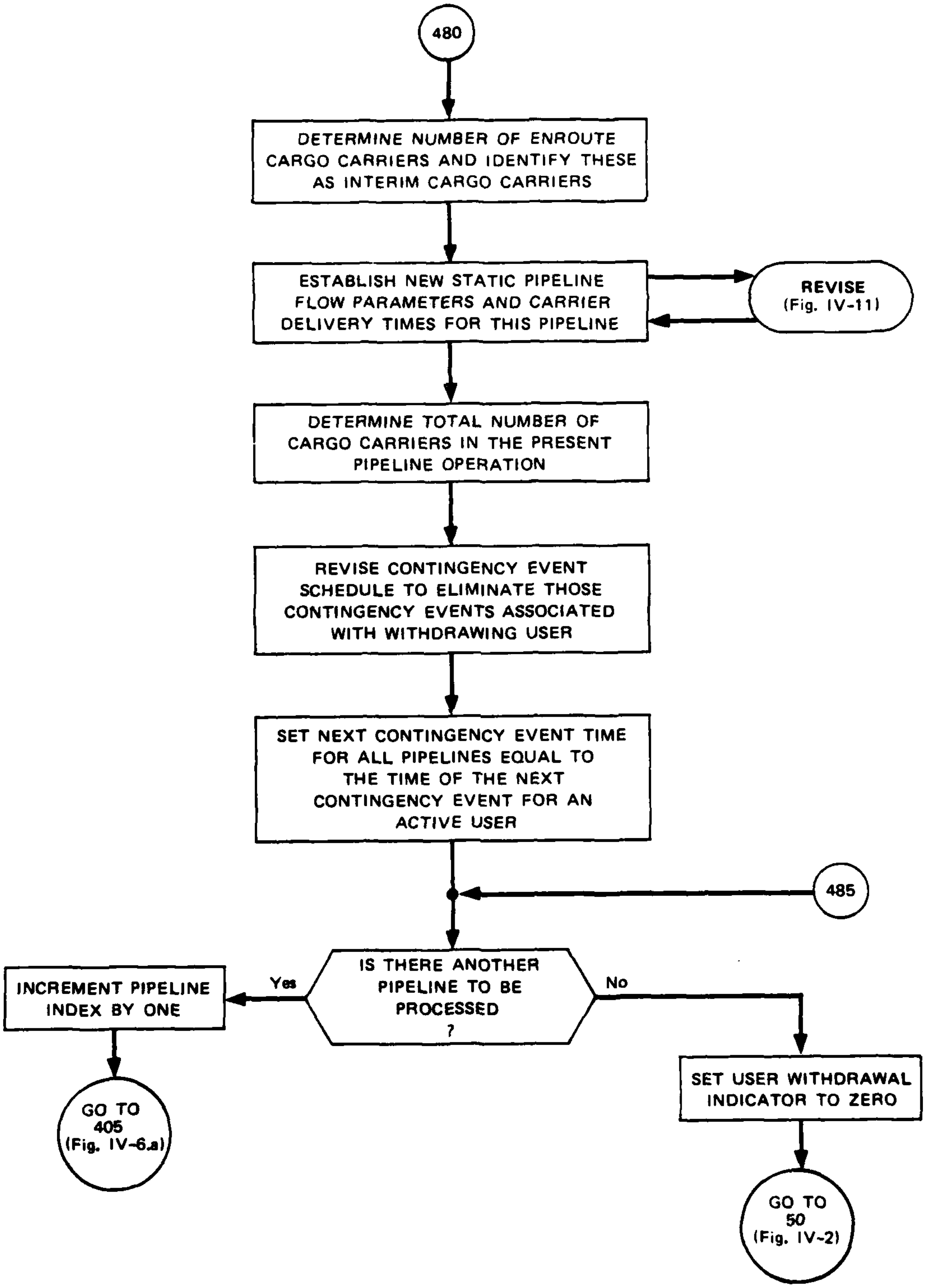

FIGURE IV-6.c LOGIC FLOWCHART (USER WITHDRAWAL PROCESSING)

and return to a safe haven. Thus, the user is assumed to withdraw, and its demands on the ISP no longer have to be satisfied. At this time, the withdrawing user's in-game indicator BIG(JE) is set equal to zero, and the user withdrawal indicator IW is set equal to one. Because a user withdrawal will affect each pipeline operation, all three pipelines are subjected to processing for this event. The module thus sets P=1 and begins the event processing for the first pipeline.

The module first stores the previous values of the pipeline's supply rate SROLD, the total demand rate MDOLD, and the cargo carrier load CLOLD, for the static pipeline operation. That is,

$$SROLD = SR(P) \tag{IV-29}$$

$$MDOLD = MD(P) \tag{IV-30}$$

$$CLOLD = CL(P) \tag{IV-31}$$

Next, the message "SUPPLY LEVEL REACHES CRITICAL LEVEL USER NUMBER JE, USER WITHDRAWALS--INSTIGATING PIPELINE-PN(JP)" on the Event Chronologies for each pipeline, where JE denotes the index of the instigating user and JP denotes the pipeline associated wiith the supply shortfall. If the pipeline being processed is not the one causing the withdrawal event, the present ISP and user supply levels are determined in accordance with Eq. (IV-13) and (IV-14). These are then printed out on the Event Sequenced Supply Level table for this pipeline (for the pipeline causing this event, this supply level printout was already done in Control). Next, the time of last event for this pipeline TLE(P) is set equal to the current time, CT. The module then computes

the new total demand rate by subtracting out the withdrawing user's demand rate. Thus,

$$MD(P) = MD(P) - BR(JE,P) \qquad \text{(IV-32)}$$

The instigating user is now withdrawn from the pipeline operation by setting its supply rate BS(JE,P), its demand rate BR(JE,P), and its next event type SE(JE,P) to zero. Also, this user's next event time TE(JE,P) is set equal to a large number.

The module then checks to see if all users have now withdrawn. If so, the event type ET is set equal to seven and the message "RUN TERMINATED--ALL USERS HAVE WITHDRAWN" is printed out on the Event Chronologies for each pipeline. In addition, the supply level will be printed out on the Event Sequenced Supply Level table for each pipeline, and the supply rates will be printed out on the Supply Rate Variation table for each pipeline. The module then proceeds to Output Processing (Section 10).

If there are still active users, the module then checks to see if the pipeline being processed is the one causing the user withdrawal. If it is not, the processing is transferred to the Contingency Event Processing (Section 7), where the processing parallels that of a contingency event in which a user's demand rate is decreased. The processing activity is described in that section. If this is the pipeline causing the user withdrawal, the module then determines if the revised user total demands can now be satisfied by the ISP. If this is not the case, then the module determines new supply rates for each active user in this pipeline and then establishes the next event types and times of each user relative to the pipeline being processed. These are done in the same manner as that described at the end of Section 3 (Cargo Carrier Processing).

If user's demands can be met, then the ISP supply rate SR(P) is set equal to the total demand rate MD(P), each active user's supply rate BS(I,P) is set equal to its demand rate

BR(I,P), and their next event times TE(I,P) are set equal to a large number. With the withdrawal of a user, a supply surplus may possibly be accumulated before the arrival of the next cargo carrier. If this is the case (SROLD > MD(P)), then the amount of supply surplus is determined by the following equation:

$$SFM = (SROLD - MD(P)) \bullet (DT(1,P) - CT) \qquad \text{(IV-33)}$$

This supply surplus is then distributed to the active users according to the procedures described in Subroutine SHTFAL (Section 14). Because user supply levels have changed, these new supply levels are printed out on the Event Sequenced Supply Level table for this pipeline.

In each case above involving active users, the ISP and user supply rates have changed. These are now printed out on the Supply Rate Variation table for this pipeline. The next step is to determine the number of enroute cargo carriers. To do this, it is first required to determine the arrival time of a hypothetical cargo carrier that would be in a load preparation at the time that a revised supply order would be received at the supply source. This arrival time is determined as follows:

$$TEM = CT + CLOLD \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)} \right) + \frac{MSD(P)}{24 \bullet SCS(P)} + MOT(P) \qquad \text{(IV-34)}$$

where CLOLD is the previous static pipeline cargo carrier load for this pipeline, MOT(P) is the ISP order time, and the remaining variables are as indicated following Eq. (IV-5) in

Section 2. Thus, if $DT(J,P) \leq TEM$, then this Jth cargo carrier will be identified as an iterim cargo carrier and will remain in the cargo carrier arrival schedule. The number of interim cargo carriers NIC(P) will be set equal to the total number of such cargo carriers. Subroutine REVISE (Section 11) will then be called upon to establish the new static pipeline flow parameters: that is, the number of cargo carriers required to maintain the pipeline operation NC(P); the cargo carrier load for each of these carriers CL(P); and the separation time between cargo carriers TR(P). The total number of cargo carriers in the pipeline operation NTC(P) is then determined as follows:

$$NTC(P) = NIC(P) + NC(P) + 1 \qquad \text{(IV-35)}$$

where it should be recalled that one extra cargo carrier is scheduled in the normal pipeline operation. The scheduled arrival at the ISP of the static pipeline cargo carriers and their associated loads must now be established. These are given as follows, where J ranges from 1 to NC(P) + 1:

$$DT(NIC+J,P) = DT(NIC(P),P) + J \bullet TR(P) \qquad \text{(IV-36)}$$

$$DC(NIC+J,P) = CL(P) \qquad \text{(IV-37)}$$

Since a user withdrew, any shceduled contingency event associated with this user must be cancelled. This cancellation process proceeds as follows. A no-event indicator IJ is initially set equal to zero. If there are no more scheduled contingency events (NCO > NOC), the the time of the next contingency event TE(NB2,P) for each pipeline is set equal to a large number. If there are more scheduled contingency events, then a test is made to determine, in sequence, if the scheduled contingency event involves the withdrawing user. If the answer is no, then nothing is done. If the answer is yes, then that contingency event is eliminated from the contingency event

schedule, and the remaining contingency events are moved up in the scheduling arrays. If JJ denotes the contingency index number of the contingency to be cancelled, then for J = JJ to NOC and for all 1P,

$$TC(JJ) = TC(JJ+1) \quad \text{(IV-38)}$$

$$CUN(JJ) = CUN(JJ+1) \quad \text{(IV-39)}$$

$$CUD(JJ,P) = CUD(JJ+1,P) \quad \text{(IV-40)}$$

$$CUP(JJ,P) = CUP(JJ+1,P) \quad \text{(IV-41)}$$

The total number of contingency events NOC is reduced by one for each cancellation and if there is another contingency event involving an active user, then the no-event indicator IJ is set equal to one. If there still is a scheduled contingency event involving the event, then the next contingency event time TE(NB2,P), for each pipeline, is set equal to the time of the next scheduled contingency event. Otherwise, this variable is set equal to a large number for each pipeline.

At this juncture, the processing of pipelines not causing the user withdrawal returns from the processing that was conducted in the Contingency Event Proceessing section. If there is another pipeline to be processed, then the pipeline index is incremented by one and this pipeline is processed as described above, beginning with the second paragraph of this section. Otherwise, the user withdrawal indicator IW is set equal to zero and the module returns to Control (Section 2) to determine the next event to be processed. This completes the User Withdrawal processing function.

7. <u>Contingency Event Processing (Fig. IV-7)</u>

When a contingency event occurs, each pipeline may or may not be affected. Thus, each pipeline will be subjected to

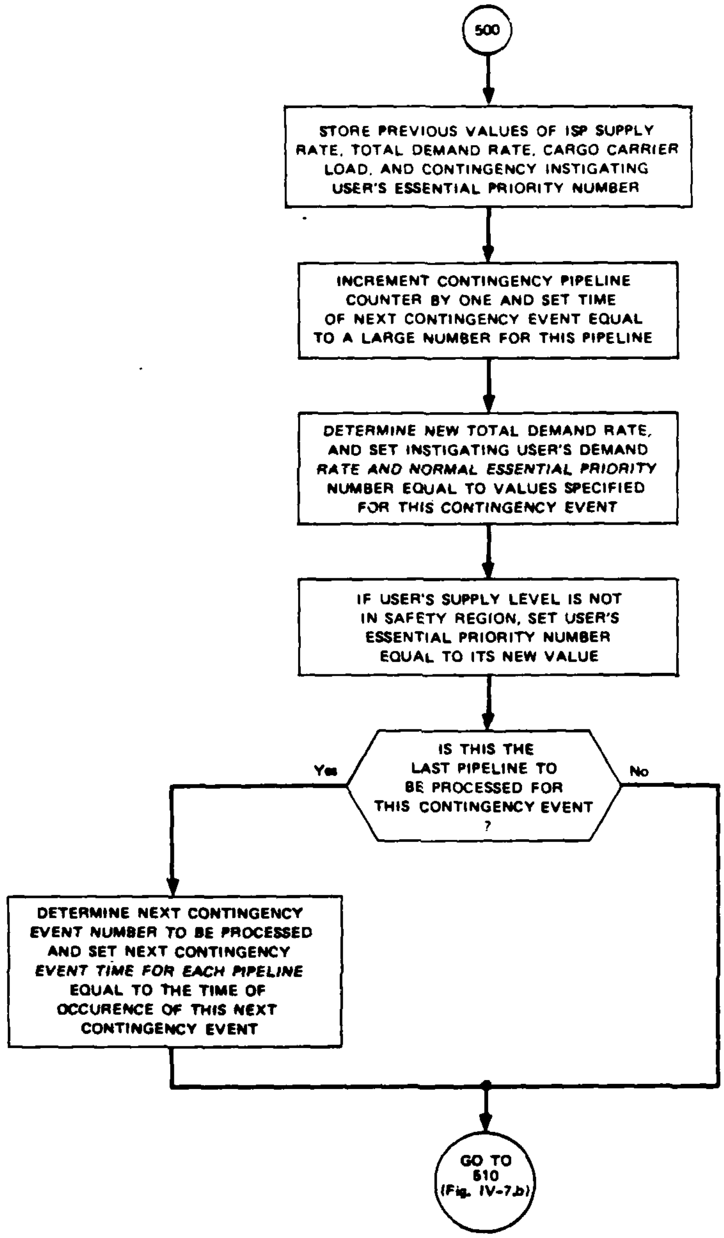

FIGURE IV-7.a LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

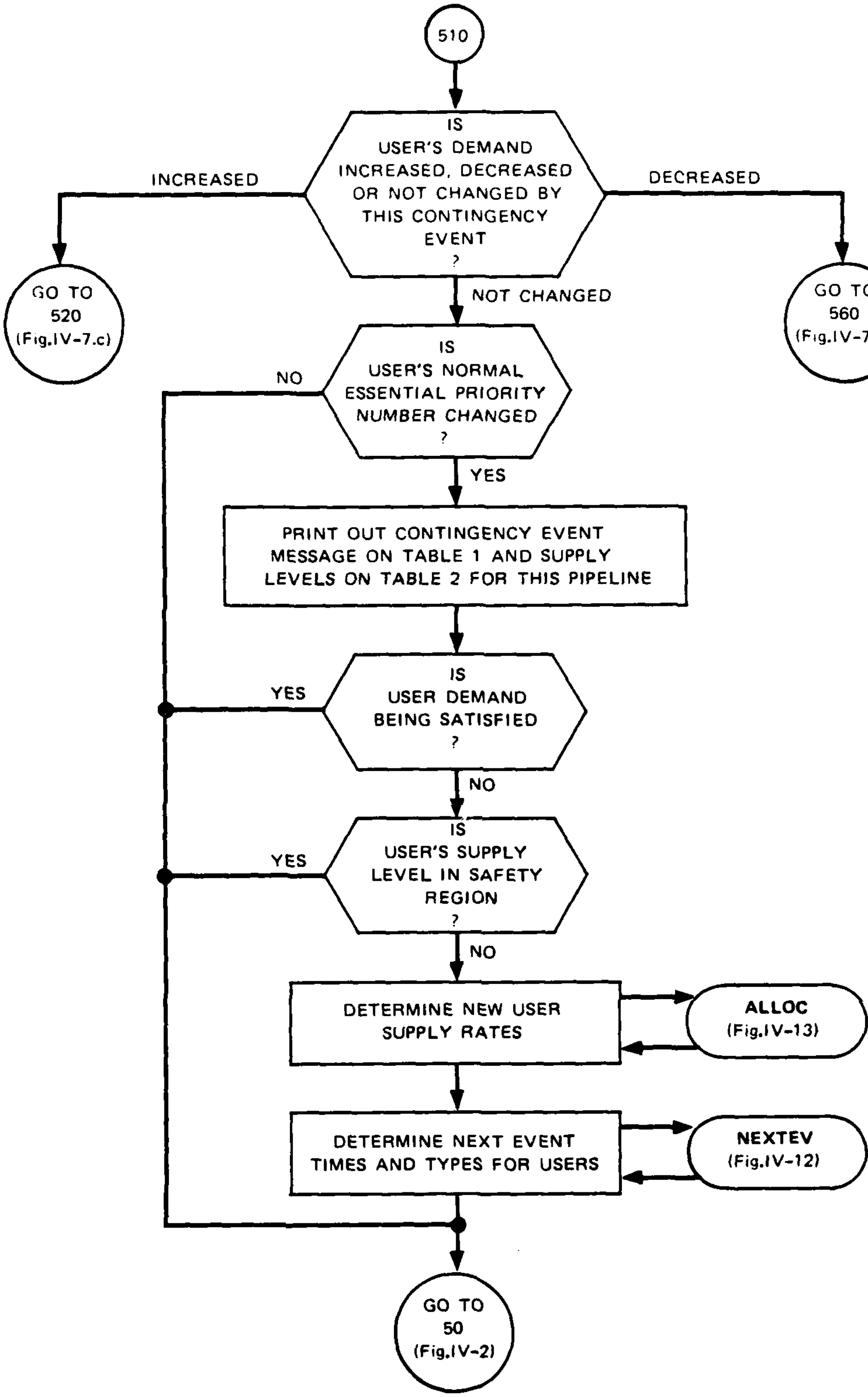

FIGURE IV-7.b LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

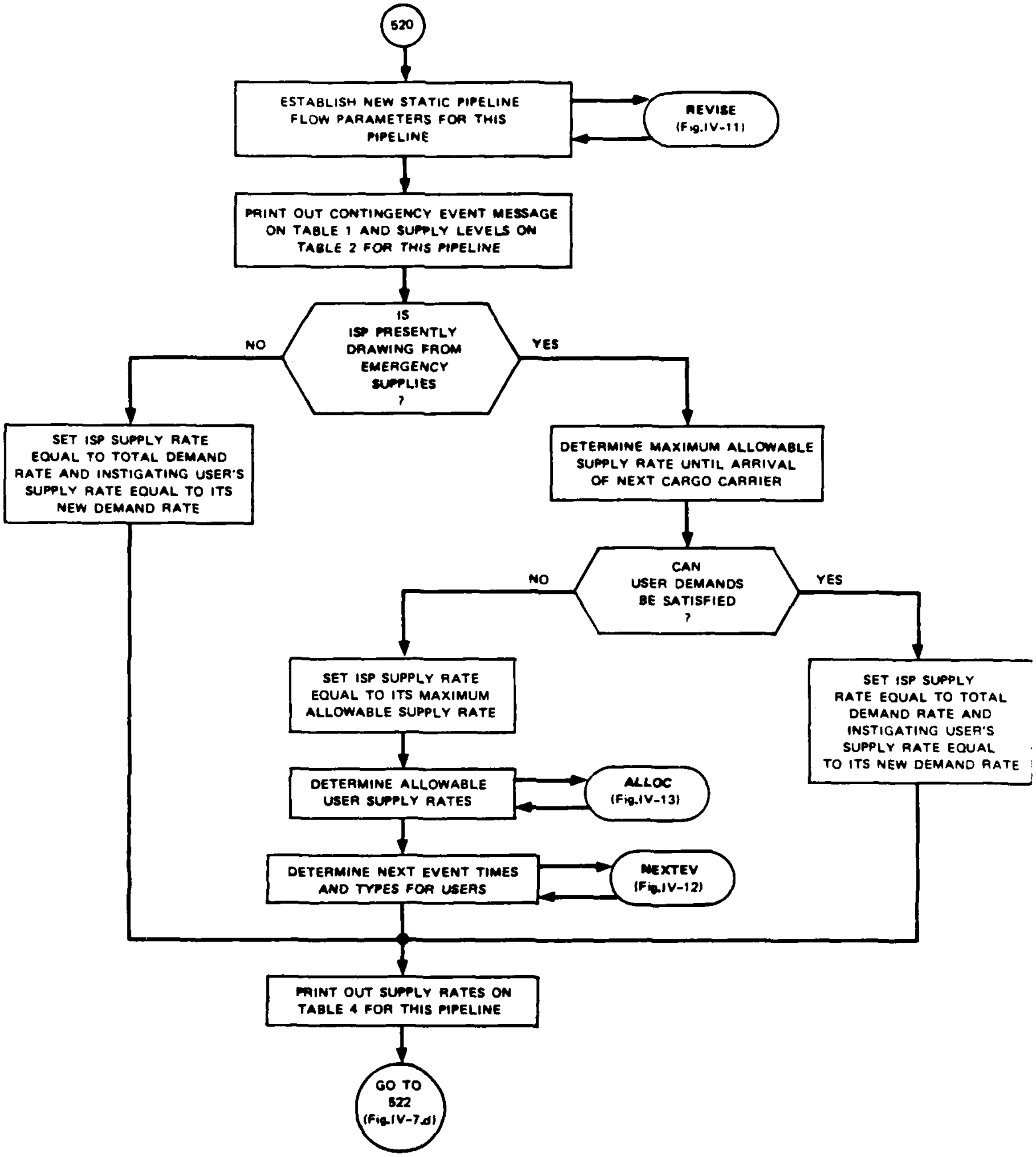

FIGURE IV-7.c LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

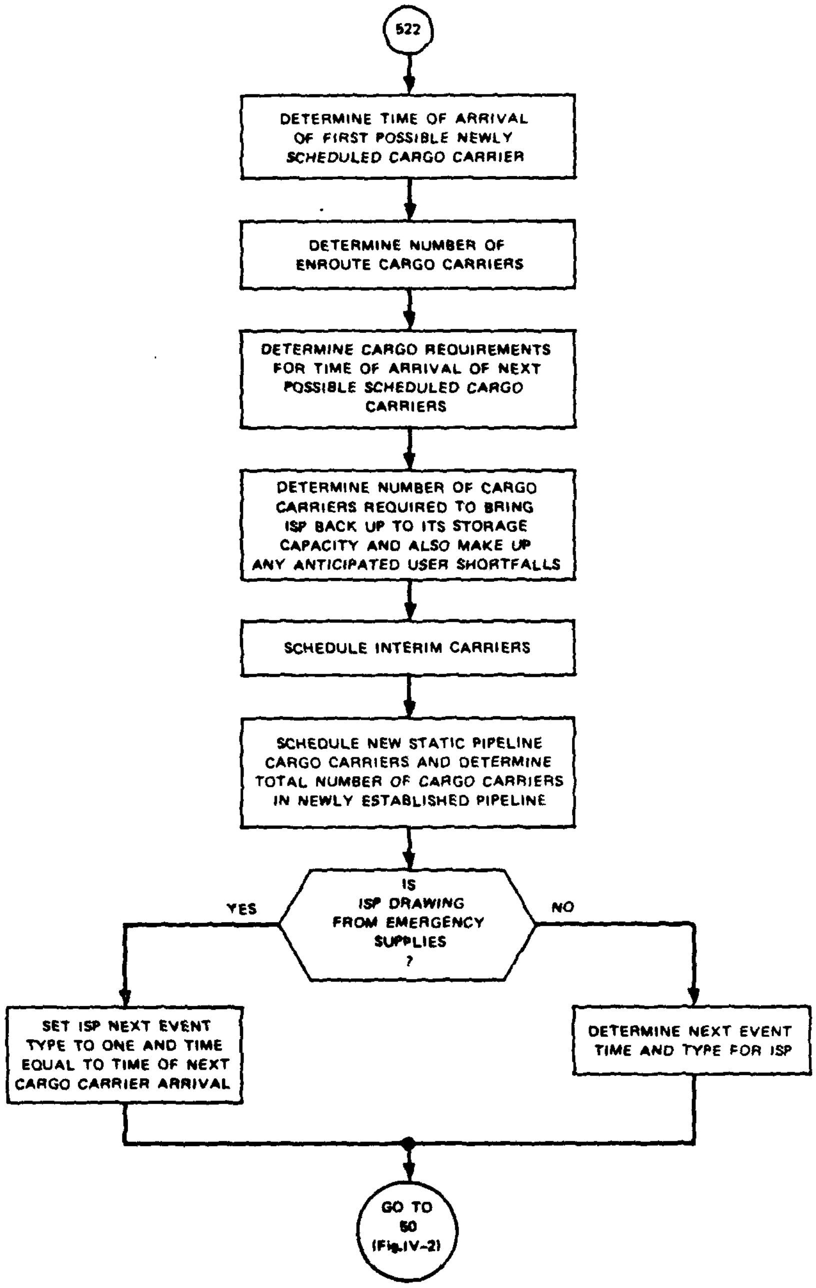

FIGURE IV-7.d LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

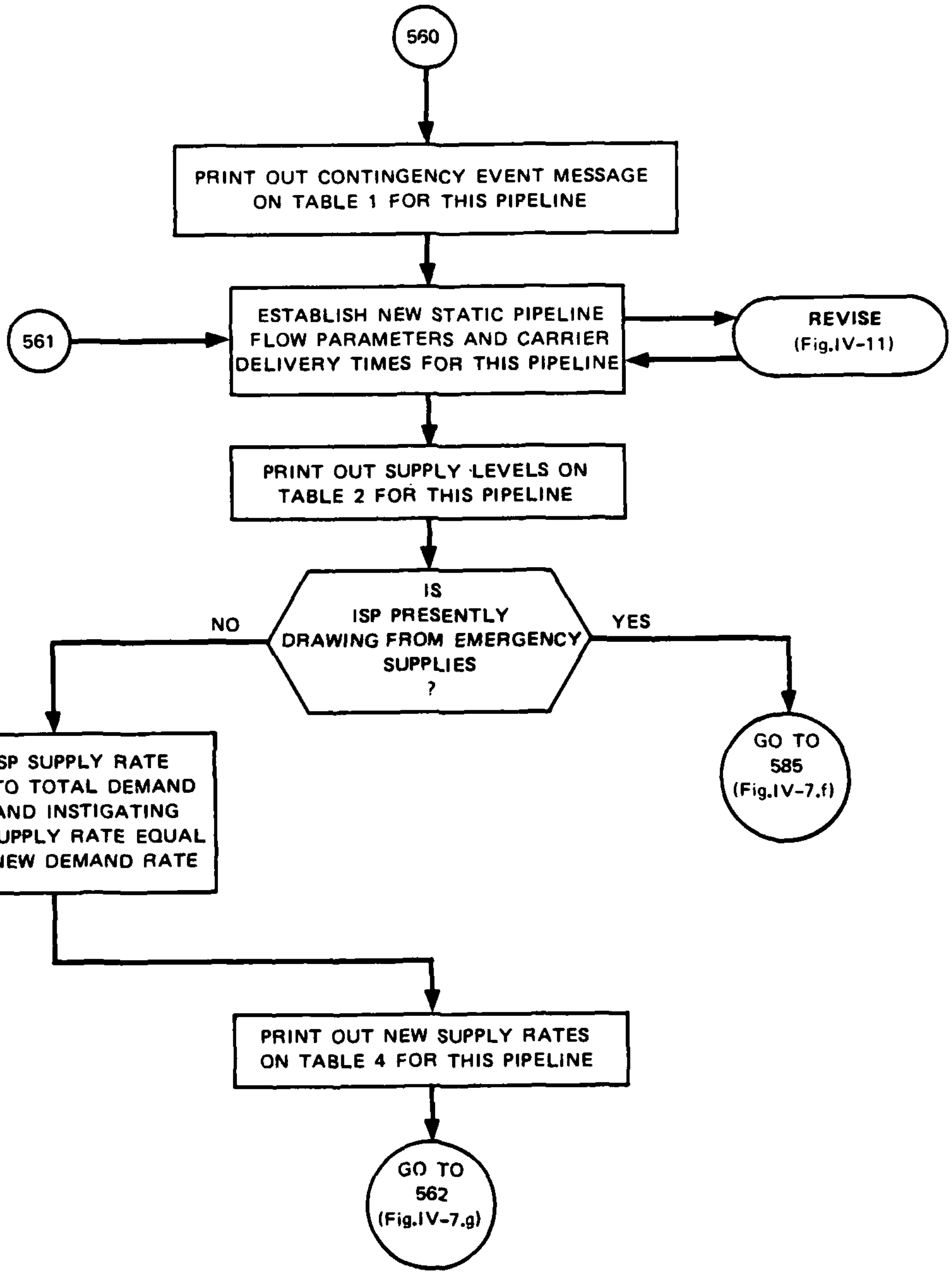

FIGURE IV-7.e LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

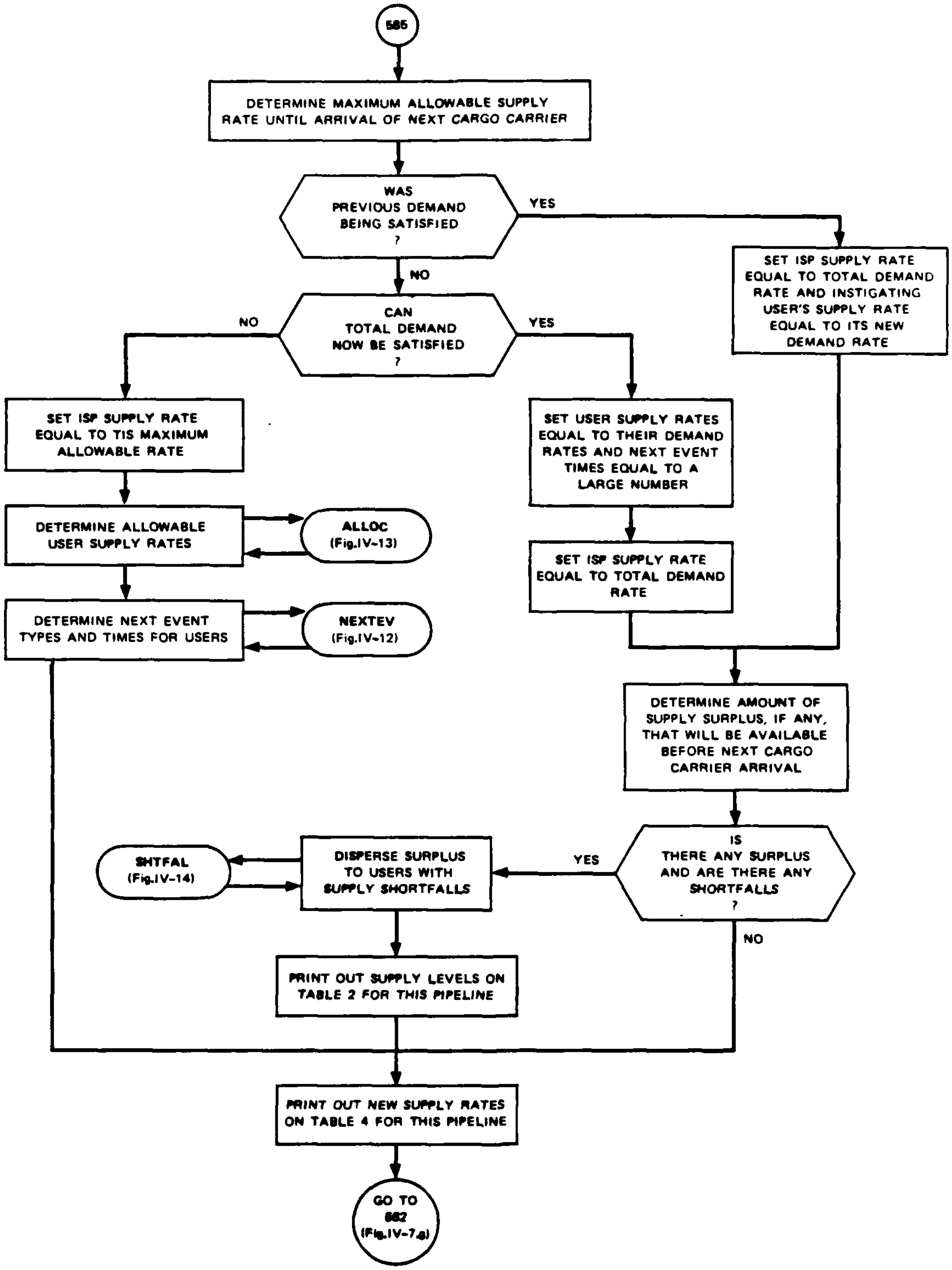

FIGURE IV-7.f LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

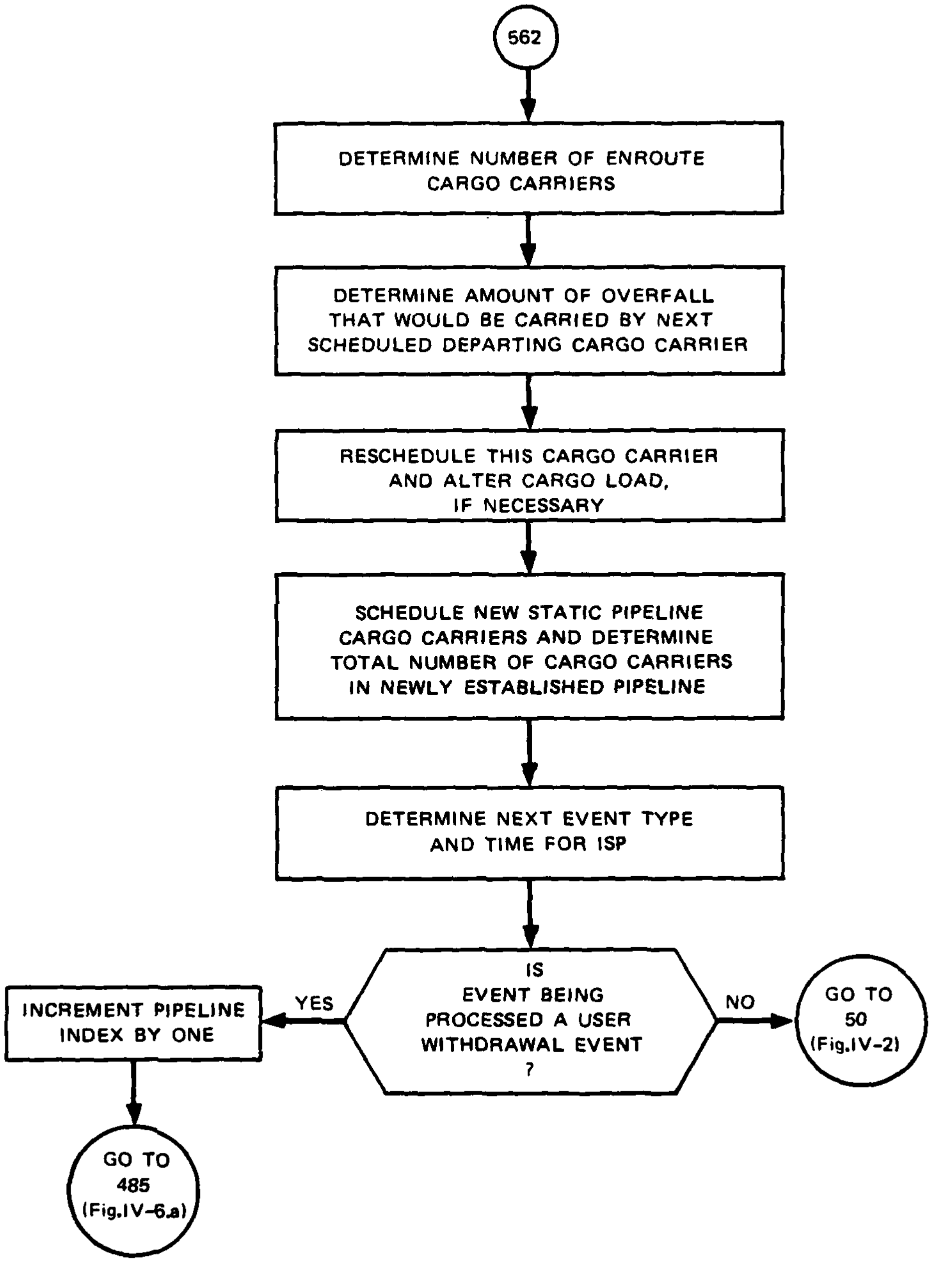

FIGURE IV-7.g LOGIC FLOWCHART (CONTINGENCY EVENT PROCESSING)

independent processing at the time of occurrence of a contingency. That is, three contingency events are scheduled, one for each pipeline, at the time of occurrence of a contingency. The processing of one of these events is described now.

The variable JE is used to denote the user instigating the contingency event, so this is set equal to CUN(NCO). The module then stores the previous values of the ISP supply rate BSOLD, the total demand rate MDOLD, the static pipeline cargo carrier load CLOLD and the instigating user's essential priority BPOLD. The contingency pipeline counter IC is incremented by one and the time of the next contingency event for the pipeline P being processed TE(NB1,P) is temporarily set equal to a large number. The module next determines the possibly new total demand rate MD(P) as follows:

$$MD(P) = MD(P) - BR(JE,P) + CUD(NCO,P) \qquad (IV\text{-}42)$$

where CUD(NCO,P), a program input, is the instigating user's possibly new demand rate. This demand rate could be the same as before, if the contingency only reflects a change in the user's essential priority or if this pipeline is not affected by the contingency. The instigating user's demand rate BR(JE(P) is then set equal to its possibly new value CUD(NCO,P), and its normal essential priority BIP(JE,P) is set equal to its possibly new value CUP(NCO,P). If the user's supply level is not in the safety region, then the user's actual essential priority BP(JE,P) is also set equal to CUP(NCO,P).

If this is the last pipeline to be processed for this contingency (IC=3), then the next contingency to be processed is determined. The contingency event counter NCO is incremented by one, and then a check is made to determine if there is another scheduled contingency. If not (NCO > NOC), then the time of occurrence of the next contingency event TE(NB2,IP) is set equal to a large number for each pipeline IP (recall that the index P

at this point refers only to the pipeline being processed). Otherwise, a check is made to determine if the next scheduled contingency involves an active user (BIG(CUN(NCO)) = 1). If not, the contingency event counter is incremented by one, and the procedure described immediately above is repeated. Otherwise, the next contingency event time TE(NB2,IP) for each pipeline IP is set equal to the time of occurrence of the next contingency TE(NCO).

Whether or not this is the last pipeline to be processed for this contingency, the module processing proceeds in the following manner. A test is made to determine if the instigating user's demand rate for this pipeline increased (MD(P) > MDOLD), decreased (MD(P) < MDOLD), or remained the same (MD(P) = MDOLD). Each of these cases requires different processing.

The simplest case is when the user's demand rate remained the same. A test is then made to determine if the user's normal essential priority changed (BIP(JE,P) BPOLD). If not, then this contingency does not affect the pipeline being processed and the module returns to control (Fig. IV-2) to determine the next event to be processed. Otherwise, the message "CONTINGENCY EVENT--USER NUMBER JE" is printed out on the Event Chronology for this pipeline, where JE denotes the index of the instigating user. Also, the supply levels are printed out on the Event Sequenced Supply Level table for this pipeline. If demand is being satisfied (SR(P) = MD(P)), or if the instigating user's supply level is in the safety region (SE(JE,P) = 4)so that its present essential priority is at the maximum value of unity), then this change in the normal essential priority for this user will not affect the present pipeline operation. Thus, the module returns to Control (Section 2) to determine the next event to be processed. Otherwise, this change in the normal essential priority will affect the pipeline operation through the alteration of the user supply rates, which are presently less than their respective demand rates and, as such, are dependent on the user's essential priorities. The module then proceeds to

determine new supply rates for each active user in this pipeline and then establishes the next event types and times of each user relative to the pipeline being processed. These are done in the same manner as that described at the end of Section 3 (Cargo Carrier Processing). The module then returns to Control (Section 2) to determine the next event to be processed. This completes this portion of the Contingency Event Processing.

If the instigating user's demand rate for this pipeline increased due to this contingency, the module processing proceeds in the following manner. First, the message "CONTINGENCY EVENT--USER NUMBER JE" is printed out on the Event Chronology for this pipeline, and the supply levels are printed out on the Event Sequenced Supply Level table for this pipeline. The next function is to establish, by calling on Subroutine REVISE (Section 11), the new static pipeline flow parameters: that is, the number of cargo carriers required to maintain the static pipeline operation NC(P); the cargo carrier load for each of these carriers CL(P); and the separation time between cargo carriers TR(P). The module then checks to see if the ISP is drawing from its emergency supplies (ESP(P) = 1). If not, the ISP supply rate is set equal to the new total demand rate (SR(P) = MD(P)), and the instigating user's supply rate is set equal to its new demand rate (BS(JE,P)). If the ISP is drawing from emergency supplies, then the next step is to determine the maximum allowable supply rate, SRT, which is computed as indicated previously in Eq. (IV-26) in Section 3. If user demands can still be satisfied (SRT $\geq$ MD(P)), then the ISP supply rate is set equal to the new total demand rate, and the instigating user's supply rate is set equal to its new demand rate, as indicated above. If user demands cannot be satisfied, then the ISP supply rate is set equal to its maximum allowable value (SR(P) = SRT). The module then determines the allowable user supply rates and the next event times and types for each user relative to the pipeline being processed, in the manner as that described at the end of Section 3 (Cargo Carrier

Processing). For all the cases described in this paragraph, the module then prints out the new supply rates on the Supply Rate Variation table for this pipeline.

The next function is to set up a new cargo carrier arrival schedule. The first step is to determine the time of arrival, TFA, of the first possible newly scheduled cargo carier. This is given by the following equation:

$$TFA = CT + SCC(P) \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)} \right) + \frac{MSD(P)}{24 \bullet SCS(P)} + MOT(P) \qquad (IV-43)$$

The next step is to determine the number of enroute cargo carriers. This requires the determination of the time of arrival, TEM, of a hypothetical cargo carrier that would be in load preparation at the time that a revised supply order would be received at the supply source. This is computed the same as TFA above in Eq. IV-43, with the exception that SCC(P) is replaced by CLOLD, the previous static pipeline cargo carrier load. The previous cargo carrier arrival DT(J,P) is then compared with TEM. If DT(J,P) $\leq$ TEM, then this Jth cargo carrier will be identified as an interim cargo carrier and will remain in the cargo carrier arrival schedule. The number of interim cargo carriers NIC(P) will be set equal to the total number of such cargo carriers. Since there has been an increase in demand, these interim cargo carriers will not carry sufficient supplies to meet demand during the interim period. Thus the amount of expected shortfall, CAR, that will have to be made up is now computed in the following manner. Let TSA denote the time of arrival of the next scheduled

non-enroute cargo carrier, and let CLP denote its cargo load, that is

$$TSA = DT(NIC(P)+1,P) \tag{IV-44}$$

$$CLP = DC(NIC(P)+1,P) \tag{IV-45}$$

Then

$$CAR = CLP + (MD-MDP)\bullet(TSA-CT) \tag{IV-46}$$

where CAR actually includes some extra shortfall that would accumulate in the time interval from the time of arrival of the first possible newly scheduled cargo carrier, TFA, to the time of arrival of the next scheduled non-enroute cargo carrier, TSA. This is accounted for in scheduling new interim cargo carriers, as will now be described.

The number of new interim cargo carriers required, denoted for the present by the dummy variable TEM, is computed as follows:

$$TEM = \frac{CAR - MD(P)\cdot(TSA-TFA)}{SCC(P)} \tag{IV-47}$$

Now TEM may not be an integer variable. Let ITEM be the smallest integer equal to or less than TEM. Then, this number of cargo

carriers will be scheduled immediately. Hence, they will arrive at the ISP at time TFA. Thus,

$$DT(NIC(P)+J,P) = TFA \tag{IV-48}$$

$$DC(NIC(P)+J,P) = SCC(P) \tag{IV-49}$$

where J ranges from 1 to ITEM. If TEM happened to attain an integer value, then no more interim carriers will be scheduled and the number of interim carriers NIC(P) in the new pipeline will be given as follows:

$$NIC(P) = NIC(P) + ITEM \tag{IV-50}$$

If TEM is not integer-valued, then one more interim cargo carrier must be scheduled, but it will have a greater time of arrival than TFA. To determine this time of arrival, it is first required to determine the time of arrival, TL, of the previous departing cargo carrier. If ITEM was greater than zero, then TL = TFA. If not, then TL = DT(NIC(P),P) if there are enroute cargo carriers, or if there are no enroute cargo carriers, then

$$TL = CT - \frac{MSC(P) - SL(P)}{\dot{M}D(P)} \tag{IV-51}$$

a fictitious time of arrival of a previous cargo carrier, at present demand rate, that if fully loaded would arrive in time with the proper load. At this point, the number of additional interim cargo carriers ITEM is increased by one to account for this one presently being scheduled. That is,

$$\mathrm{ITEM} = \mathrm{ITEM} + 1 \tag{IV-52}$$

Next, the required time of arrival TLA of this last interim cargo carrier, given a full cargo load, is determined as follows:

$$\mathrm{TLA} = \mathrm{TSA} - \frac{\mathrm{CAR{-}ITEM} \cdot \mathrm{SCC(P)}}{\mathrm{MD(P)}} \tag{IV-53}$$

It is now required to check if the interval of time between arrival of this last interim cargo carrier and the previous arriving one (TLA-TL) is greater than the new separation time between arrivals TR(P) of cargo carriers in the static pipeline. If not, this last interim carrier is scheduled to arrive at time TLA with a full cargo load. That is,

$$\mathrm{DT(NIC(P)+ITEM,P)} = \mathrm{TLA} \tag{IV-54}$$

$$\mathrm{DC(NIC(P)+ITEM,P)} = \mathrm{SCC(P)} \tag{IV-55}$$

If (TLA-TL) is greater than TR(P), then the cargo carrier will be scheduled to arrive sooner with a less-than-full cargo load, but

not before the time of the first possible newly scheduled cargo carrier arrival TFA. Let the dummy variable TEM be determined as follows

$$TEM = \max\{TL+TR,\ TFA\} \qquad (IV-56)$$

Then the scheduled time of arrival and cargo load of this last scheduled interim cargo carrier are given as follows:

$$DT(NIC(P)+ITEM,P) = TEM \qquad (IV-57)$$

$$DC(NIC(P)+ITEM,P) = SCC(P) - MD(P)\bullet(TLA-TEM) \qquad (IV-58)$$

The number of interim cargo carriers in the pipeline NIC(P) is now determined according to Eq. (IV-50), specified previously in this section. This completes the scheduling of interim cargo carriers for the new pipeline.

The next step is to schedule the new static pipeline cargo carriers. The static pipeline flow parameters (NC(P), TR(P), and CL(P)) were established earlier in the processing of this increase-in-demand case. The scheduled arrival times and cargo loads of these carriers are given as follows:

$$DT(NIC(P)+J,P) = DT(NIC(P),P) + J\bullet TR(P) \qquad (IV-59)$$

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$$DC(NIC(P)+J,P) = CL(P) \qquad \text{(IV-60)}$$

where J ranges from 1 to NC(P)+1. The total number of cargo carriers NTC(P) in the pipeline is also determined by the following equation:

$$NTC(P) = NIC(P) + NC(P) + 1 \qquad \text{(IV-61)}$$

The final step is to determine the next event type and time for the ISP. If the ISP is presently drawing from emergency supplies (ESP(P) = 1), then the next event type will be a cargo carrier arrival (SE(NB1,P) = 1), and the time of occurrence will be the arrival time of the next cargo carrier (TE(NB1,P) = DT(1,P)). Otherwise, it must be determined if the next cargo carrier will arrive before the ISP would have to begin drawing from its emergency supplies. Let TEM denote this time, then

$$TEM = CT + \frac{SL(P)-MES(P)}{MD(P)} \qquad \text{(IV-62)}$$

If TEM is greater or equal to the time of arrival of the next cargo carrier, then the next ISP event will be the arrival of the cargo carrier (SE(NB1,P) = 1 and TE(NB1,P) = DT(1,J)). Otherwise, the next event will be the ISP drawing from its emergency supplies (SE(NB1,P) = 2 and TE(NB1,P) = TEM).

At this point, the module returns to Control (Section

2) to determine the next event to be processed. This completes this portion of the Contingency Event Processing.

If the instigating user's demand rate for this pipeline decreased due to this contingency, the module processing proceeds in the following manner. First, the message "CONTINGENCY EVENT--USER NUMBER JE" is printed out on the Event Chronology for this pipeline. At this point, the processing of a user withdrawal for the non-instigating pipeline parallels the Contingency Event processing. Here, the User Withdrawal Processing (Section 6) is transferred to this processing section of the module. The module next prints out the supply levels on the Event Sequenced Supply Level table for this pipeline.

If the ISP is not drawing from its emergency supplies (ESP(P) = 0), then the ISP supply rate SR(P) is set equal to the new total demand rate MD(P), and the instigating user's supply rate BS(JE,P) is set equal to its new demand rate BR(JE,P). The new supply rates are then printed out on the Supply Rate Variation table for this pipeline.

If the ISP is presently drawing from its emergency supplies, then the first step is to determine its maximum allowable supply rate SRT as follows:

$$\mathrm{SRT} = \frac{\mathrm{SL(P) - MCS(P)}}{\mathrm{DT(1,P) - CT}} \tag{IV-63}$$

If total demand cannot be satisfied (SRT < MD(P)), then the ISP supply rate is set equal to the maximum allowable supply rate (SR(P) = SRT). The allowable user rates and the next event times and types for each user relative to this pipeline are then determined in the manner described at the end of Section 3 (Cargo

Carrier Arrival Processing).

If total demand can be satisfied, the ISP supply rate is set equal to the total demand rate (SR(P) = MD(P)), and the user supply rates are set equal to their demand rates (BS(I,P) = BR(I,P)). Also, the users' next event times TE(I,P) are all set equal to a large number. With a decrease in demand, a supply surplus may be accumulated before the arrival of the next cargo carrier. If this is the case (SRT > MD(P)), then the amount of supply surplus SFM is determined by the following equation:

$$\text{SFM} = (\text{SRT-MD(P)}) \bullet (\text{DT(1,P)-CT}) \qquad \text{(IV-64)}$$

This supply surplus is then distributed to the active users, in accordance with the procedures described in Subroutine SHTFAL (Section 14). Because user supply levels have changed, these new supply levels are printed out on the Event Sequenced Supply Level table for this pipeline.

In the above cases where the ISP was previously drawing from its emergency supplies, at least one user supply rate has changed. Thus, the ISP and user supply rates are printed out on the Supply Rate Variation table for this pipeline.

For all decrease-in-demand cases, the next function is to set up a new cargo carrier arrival schedule. The first step is to determine the arrival time, TEM, of a cargo carrier that would be in load preparation when the new supply order revision is received at the supply source. This is determined by the following equation:

$$TEM = CT + CLOLD \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)} \right) + \frac{MSD(P)}{24 \bullet SCS(P)} + MOT(P) \quad \text{(IV-65)}$$

Next, the number of enroute carriers is determined. If DT(J,P) TEM, then this Jth cargo carrier will be identified as an interim cargo carrier and will remain in the cargo carrier arrival schedule. The number of interim cargo carriers NIC(P) will be set equal to the total number of such cargo carriers. Because there has been a decrease in demand, these cargo carriers will be carrying an excess of supplies, but it would be inefficient to change their already implemented schedule. However, for the next scheduled cargo carrier, this can be accomplished. First, the amount of overfall SOF that the cargo carrier would be carrying is determined in the following manner. Its present scheduled time of arrival, TN, and its cargo load, CLI, are given as follows:

$$TN = DT(NIC(P)+1,P) \quad \text{(IV-66)}$$

$$CLI = DT(NIC(P)+1,P) \quad \text{(IV-67)}$$

Also required is the time of arrival, TL, of the last interim carrier now scheduled. If there are no scheduled interim carriers, then this time of arrival is set equal to the current time for this computation. Thus,

$$TL = \begin{cases} DT(NIC(P),P) & \text{if } NIC(P) \neq 0 \\ CT & \text{if } NIC(P) = 0 \end{cases} \qquad (IV\text{-}68)$$

For subsequent computations, in the case where there are no interim cargo carriers, the variable TL is reset to the following:

$$TL = CT - \frac{MSC(P) - SL(P)}{MD(P)} \qquad (IV\text{-}69)$$

Also, at this point, the number of intrim carriers is increased by one (NIC(P)+1). The projected supply overfall, SOF, is then determined by the following equation:

$$SOF = (MDOLD - MD(P)) \bullet (TN-TL) \qquad (IV\text{-}70)$$

The scheduled arrival of this cargo carrier may be extended to the time TPA, where

$$TPA = TN + \frac{SOF + SCC(P) - CLI}{MD(P)} \qquad (IV\text{-}71)$$

This will be the case if the time interval between arrival of this last interim cargo carrier and the previous arriving one (TPA-TL) is less than or equal to the new separation time between arrivals TR(P) of cargo carriers in the static pipeline. If so, this last interim cargo carrier is scheduled to arrive at time TPA with a full cargo load. That is,

$$\mathrm{DT(NIC(P),P) = TPA} \qquad \text{(IV-72)}$$

$$\mathrm{DC(NIC(P),P) = SCC(P)} \qquad \text{(IV-73)}$$

If (TPA-TL) is greater than TR(P), then the scheduled arrival time must be decreased, accompanied by a decrease in cargo load. To accomplish this, the time of first possible arrival, TFA, which will bring the ISP supply level to its maximum, is first determined. Now the cargo load will itself be a function of TFA, that is,

$$\mathrm{CLI = SCC(P) - (TPA\text{-}TFA)\bullet MD(P)} \qquad \text{(IV-74)}$$

Substituting this in the normal equation for the time of arrival (i.e., see Eq. IV-65) results in the following equation:

$$\mathrm{FA = CT + (SCC(P) - (TPA\text{-}TFA)\bullet MD(P))\bullet\left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)}\right)}$$
$$\mathrm{+ \frac{MSD(P)}{24\bullet SCS(P)} + MOT(P)} \qquad \text{(IV-75)}$$

Solving this for TFA results in the following solution:

$$TFA = \frac{CT + (SCC(P) - TPA \bullet MD(P)) \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)} \right) + \frac{MSD(P)}{24 \bullet SCS(P)} + MOT(P)}{1 - MD(P) \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)} \right)} \qquad \text{(IV-76)}$$

The interval between arrivals must now be checked. If (TFA-TL) is greater than TR(P), then the TR(P) time requirement between arrivals cannot be satisfied. Thus, TFA, representing the arrival time of the first possible newly scheduled cargo carrier, will be the scheduled arrival time of the last interim carrier. In this case,

$$DT(NIC(P),P) = TFA \qquad \text{(IV-77)}$$

$$DC(NIC(P),P) = CLI \qquad \text{(IV-78)}$$

On the other hand, if (TFA-TL) is less than TR(P), then the scheduled arrival can be extended so that the time interval between arrivals equals TR(P). Thus,

$$DT(NIC(P),P) = TL + TR(P) \tag{IV-79}$$

$$DC(NIC(P),P) = SCC(P) - (TPA-TR(P)-TL) \bullet MD(P) \tag{IV-80}$$

This completes the scheduling of interim cargo carriers for the new pipeline.

The next step is to schedule the new static pipeline carriers, determine the total number of cargo carriers in the pipeline, and determine the next event time and type for the ISP. This is done in the manner previously descriibed in this section (see discussion surrounding Eq. (IV-59) to IV-62)).

The final step is to determine the proper return point in the module. If the event being processed is a User Withdrawal Event (IW=1), then the module returns to the end of the User Withdrawal Processing (Section 6) to determine if there is another pipeline to be processed. Otherwise (IW=0), the event being processed is a Contingency Event, and the module returns to Control (Section 2) to determine the next event to be processed.

8. <u>Routine Printout Processing (Fig. IV-8)</u>

The first step is to determine the time TEM for the next scheduled printout. This is given as follows:

$$TEM = CT+TP \tag{IV-81}$$

where TP is the input-specified printout interval. If this time is less than the scheduled run duration TDUR, then the time of the next scheduled printout is set equal to TEM. That is,

$$TE(NB3,P) = TEM \tag{IV-82}$$

Because the scheduled event type is already a Scheduled Printout

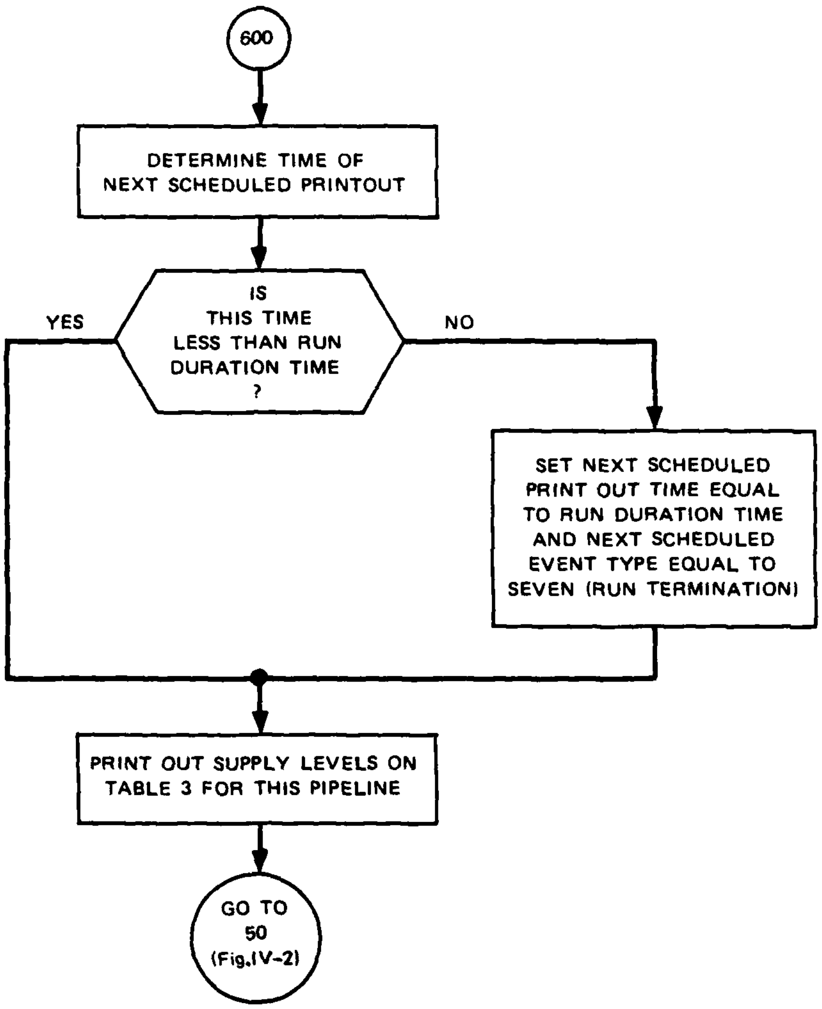

FIGURE IV-8 LOGIC FLOWCHART (ROUTINE PRINTOUT PROCESSING)

Event (SE(NB3,P) = 6), this variable need not be changed. On the other hand (TDUR $\leq$ TEM), the next scheduled event will be a Run Termination Event that will occur at time TDUR. Thus,

$$TE(NB3,P) = TDUR \tag{IV-83}$$

$$SE(NB3,P) = 7 \tag{IV-84}$$

Once the next scheduled event time and type have been established, the module prints out the supply levels on the Time Sequenced Supply Level table for this pipeline. The module then returns to Control to determine the next event to be processed.

9. Scheduled Run Termination Processing (Fig. IV-9)

When a Run Termination Event occurs, the supply levels for the pipeline whose event was chosen will already have been determined in Control processing and printed out on the Event Sequenced Supply Level table for that pipeline. The supply levels for the other pipelines are now determined in accordance with Eq. (IV-13) and (IV-14) of Section 2, and they are printed out on their respective Event Sequenced Supply Level table. The module then prints out the message "RUN TERMINATED BEFORE LAST CONTINGENCY HAS BEEN STABILIZED" on the Event Chronologies of each pipeline. In addition, the supply levels and supply rates are respectively printed out on the time Sequenced Supply Level Table and Supply Variation table for each pipeline. The module then proceeds to Output Processing (Section 10).

10. Output Processing (Fig. IV-10)

The output tables for each pipeline are stored on separate internal files. In Output Processing, the module copies these internal files, in sequential order for each pipeline, onto the final output file, which is then printed out on a line printer. This completes a module run.

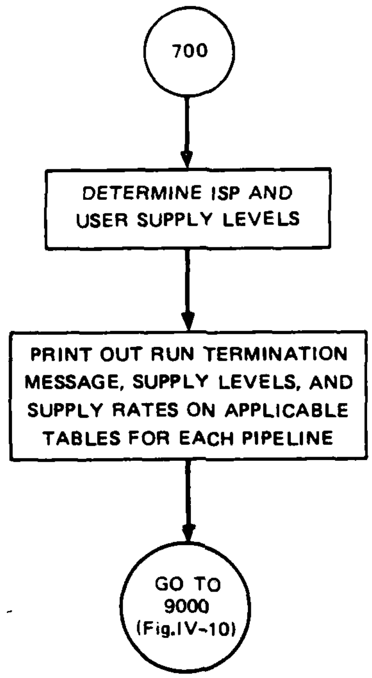

FIGURE IV-9 LOGIC FLOWCHART (SCHEDULED RUN TERMINATION PROCESSING)

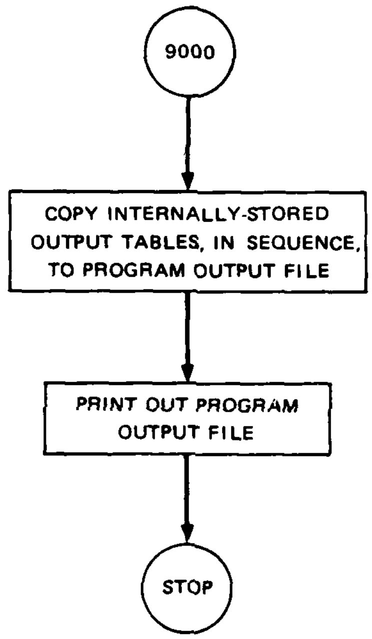

FIGURE IV-10 LOGIC FLOWCHART (OUTPUT PROCESSING)

11. <u>Subroutine REVISE (Fig. IV-11)</u>

This subroutine is called at several points throughout the main module when the demand on the ISP is altered. Its purpose is to establish static pipeline flow parameters that will satisfy this new demand. The flow parameters are: NC(P), the number of cargo carriers required to maintain the static pipeline operation; CL(P), the cargo carrier load; and TR(P), the separation time between cargo carriers.

The first step in establishing these pipeline flow parameters is to determine the maximum allowable time-between-arrivals TCM for cargo carriers so that the ISP would not have to draw from its emergency supplies during static pipeline operations. This is computed by the following equation:

$$TCM = \frac{MSC(P) - MES(P)}{MD(P)} \tag{IV-85}$$

where MSC(P) is the ISP's storage capacity, MES(P) is its emergency supply level, and MD(P) is the total demand rate on the ISP. The next step is to determine the number of supply days, TEM, that could be provided by one cargo carrier with a full load. This is given by

$$TEM = \frac{SCC(P)}{MD(P)} \tag{IV-86}$$

where SCC(P) is the cargo carrier capacity.

If this number of supply days is less than or equal to the maximum allowable time-between-arrivals (TEM $\leq$ TCM), then cargo carriers with full loads will be scheduled for the pipeline operation. Thus,

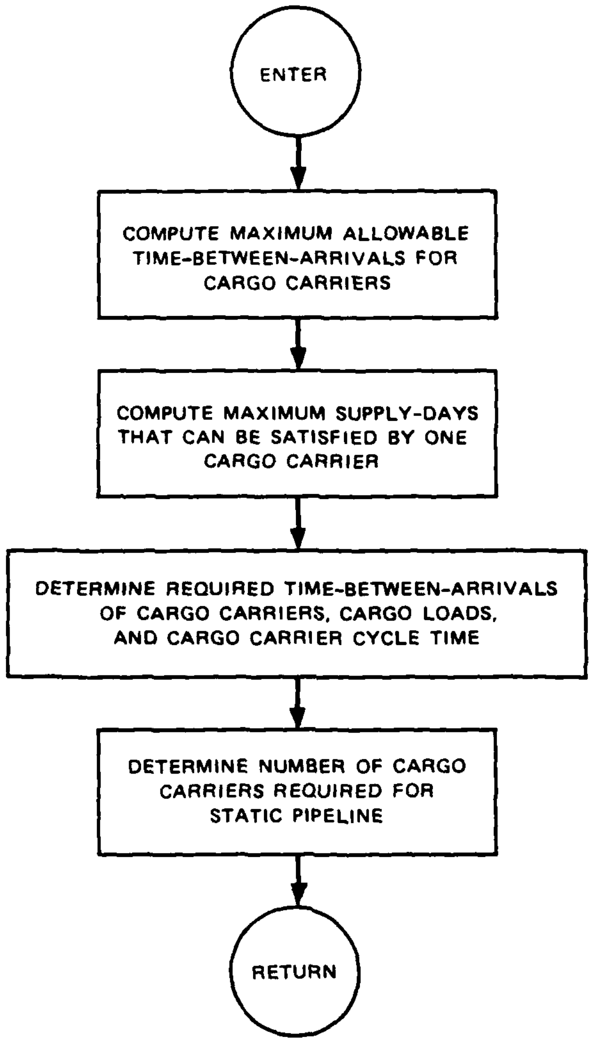

FIGURE IV-11 LOGIC FLOWCHART (SUBROUTINE REVISE)

$$TR(P) = TEM \qquad (IV-87)$$

$$CL(P) = SCC(P) \qquad (IV-88)$$

$$TCP = TCY \qquad (IV-89)$$

where TCP denotes the cargo carrier cycle time and TCY is a cargo carrier's maximum cycle time, computed in the module Initialization (see Eq. (IV-5) of Section 1). TCP is required below in determining the number of cargo carriers required to maintain the static pipeline operation.

If the number of supply days provided by a fully-loaded cargo carrier exceeds the maximum allowable time-between-arrivals (TEM > TCM), then cargo carriers with reduced loads will be required for the pipeline. Thus,

$$TR(P) = TCM \qquad (IV-90)$$

$$CL(P) = TR(P) \bullet MD(P) \qquad (IV-91)$$

$$TCP = TCY - (SCC(P) - CL(P)) \bullet \left(\frac{1}{SPR(P)} + \frac{1}{SCL(P)} + \frac{1}{MSU(P)} \right) \qquad (IV-92)$$

when SPR(P) is the cargo preparation rate, SCL(P) is the cargo loading rate at the supply source, and MSU(P) is the cargo unloading rate at the ISP.

The number of cargo carriers NC(P) requiried to maintain the pipeline is then determined as follows:

$$NC(P) = \frac{TCP}{TR(P)} \qquad (IV-93)$$

If this number is not an integer value, then one additional cargo carrier must be added to the pipeline. That is,

$$NC(P) = NC(P) + 1 \qquad \text{(IV-94)}$$

The subroutine processing is now complete, and a return is made to the main module at the subroutine calling point.

12. Subroutine NEXTEV (Fig. IV-12)

This subroutine is called upon at several points in the main module when user supply rates change and the ISP cannot meet the total demand. Its purpose is to establish the next event time and types for each active user in the pipeline. The index I denotes the user number, and it is initially set equal to one.

If the user being processed is no longer active (BIG(I) = 0), then processing proceeds to the end of the subroutine, where a check is made to see if there are any more users to be processed. If the user is active (BIG(I) = 1), then a check is made to see if the user's supply level is in its safety region, which holds true if the user's next event is a User Withdrawal Event (SE(I,P) = 4). If such is the case, then the revised time TE(I,P) for this event to occur is determined by the following equation:

$$TE(I,P) = CT + \frac{BL(I,P) - BCL(I,P)}{BR(I,P) - BS(I,P)} \qquad \text{(IV-95)}$$

where BL(I,P) denotes the user's supply level, BCL(I,P) denotes the user's critical supply level, BR(I,P) denotes the user's demand rate, and BS(I,P) denotes the user's supply rate. Otherwise, the user's next event will be the user's supply level dropping below its safety level, so that the next event indicator SE(I,P) is set equal to three. The time of occurrence for this

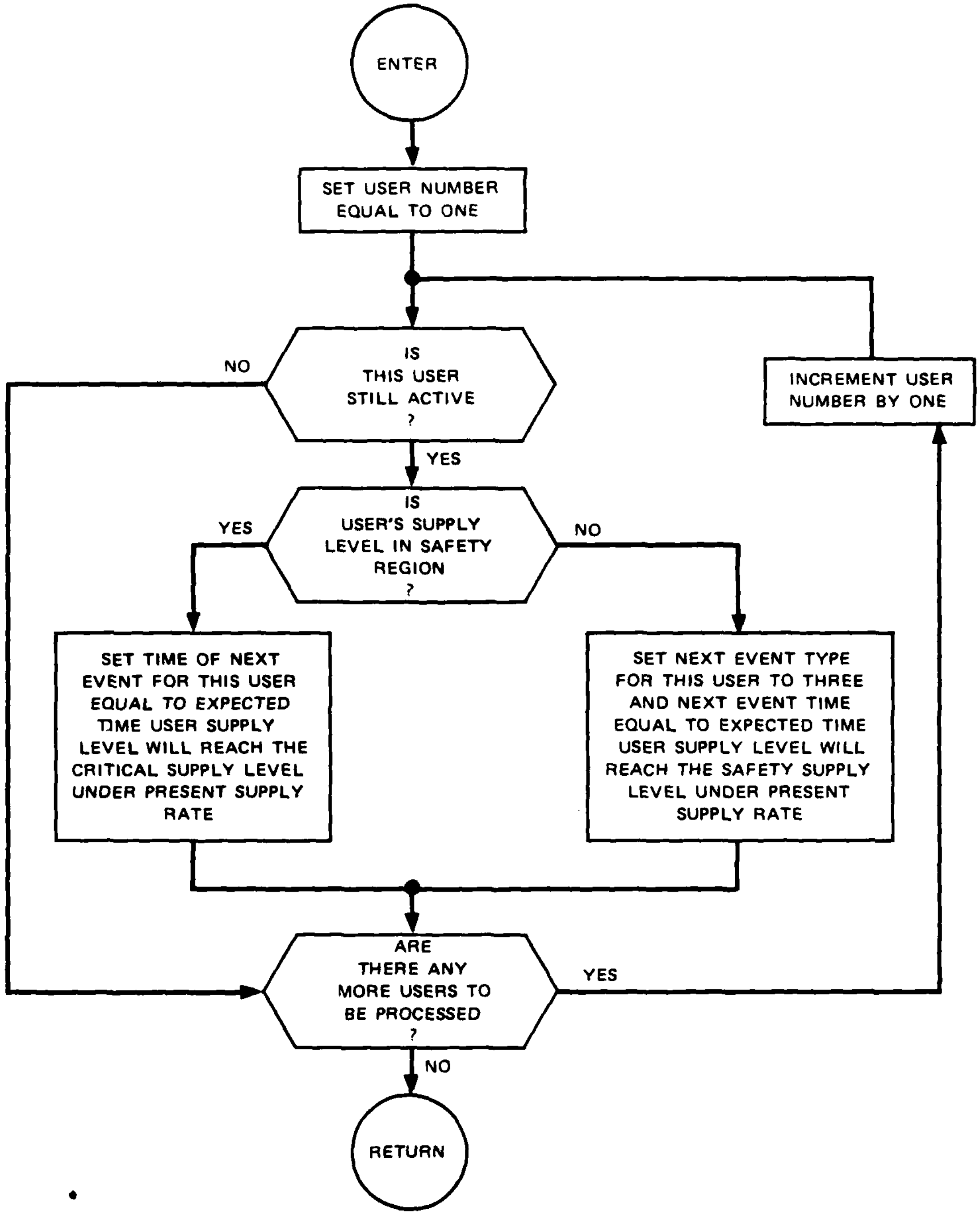

FIGURE IV-12 LOGIC FLOWCHART (SUBROUTINE NEXTEV)

event is determined as follows:

$$TE(I,P) = CT + \frac{BL(I,P) - BSL(I,P)}{BR(I,P) - BS(I,P)} \qquad (IV-96)$$

This completes the processing for this user. If there is another user, the user number index I is incremented above and the subroutine processing for this user follows that described above. If there are no more users to be processed, then the subroutine processing is complete, and a return is made to the main module at the subroutine calling point.

13. Subroutine ALLOC (Fig. IV-13)

This subroutine is called upon at several points throughout the main module when the ISP cannot meet the total demands. The purpose of this subroutine is to determine weighting factors WB(I) that determine the amount of expected shortfall to be allocated to each user. The allocation scheme used is based on the premise that the shortfall allocated to a user should be directly proportional to its demand rate BR(I,P), but inversely proportional to its essential priority (BP(I,P). Let SF(I) denote the Ith user's allocated shortfall, then this is accomplished if

$$SF(I) = K \bullet \frac{BR(I,P)}{BP(I,P)} \qquad (IV-97)$$

for all I users, where K is an unknown constant. The weighting factor WB(I) to determine for each user is such that

$$SF(I) = WB(I) \bullet TSF \qquad (IV-98)$$

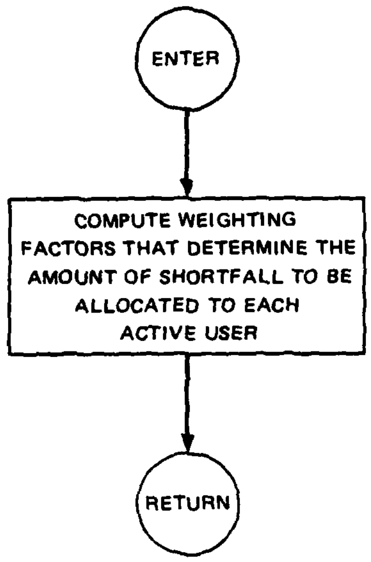

FIGURE IV-13 LOGIC FLOWCHART (SUBROUTINE ALLOC)

where TSF is the total expected shortfall. Substituting this in Eq. (IV-97) and letting K' = K/TSF results in the following set of equations:

$$WB(I) = K' \bullet \frac{BR(I,P)}{BP(I,P)} \tag{IV-99}$$

for I = 1, ... , NB, where NB is the number of users. Thus, we have NB equations with (NB+1) unknowns (the WB(I) and K'). But we must have the following condition satisfied:

$$\sum_{I=1}^{NB} WB(I) = 1 \tag{IV-100}$$

Hence, we have (NB+1) equations with (NB+1) unknowns. The solution to this set of equations, neglecting the unrequired constant K', is given by the following set of equations, one for each I=1, ..., NB:

$$WB(I) = \frac{\prod_{J \neq I} A(J)}{\sum_{I=1}^{NB} \prod_{J \neq K} A(J)} \tag{IV-101}$$

where A(J) = BP(J,P)/BR(J,P).

The above representation assumes that all users are active. In the actual processing, inactive users are not considered so that the sums and products are taken over only the active users. For inactive users, WB(I) is automatically equal to zero.

This computation of the above WB(I) factors is made in

this subroutine, and then a return is made to the main module at the subroutine calling point.

14. Subroutine SHTFAL (Fig. IV-14)

This subroutine is called on at several points in the main program when there are user shortfalls and the ISP has, or can expect, a supply surplus before the arrival of the next cargo carrier. That is, its supply level would be greater than its critical supply level when the next cargo carrier is scheduled to arrive. The purpose of this subroutine is to distribute this supply surplus to the users, taking into account the criticality of each user's shortfall.

The subroutine first determines if there are any active users whose supply levels are below their respective safety levels, which holds true if a user's next event is a User Withdrawal Event (SE(I,P) = 4). If this is the case, then the surplus is first distributed to these users to bring their supply levels up to their safety levels (if possible). First, the safety region shortfall SF(I) for each user, relative to the pipeline being processed, is determined by the following equation:

$$SF(I)=\begin{cases} BSL(I,P) - BL(I,P) & \text{if } SE(I,P) = 4 \\ 0. & \text{if } SE(I,P) \neq 4 \end{cases} \qquad \text{(IV-102)}$$

The total safety region shortfall is then given by

$$SSF = \sum_{I=1}^{NB} SF(I) \qquad \text{(IV-103)}$$

Next, it is determined whether the supply surplus, denoted by SFM, is sufficient to eliminate all the safety region shortfalls ($SFM \geq SSF$). If this does not hold, then the total surplus is proportionately distributed to these users, and their new supply

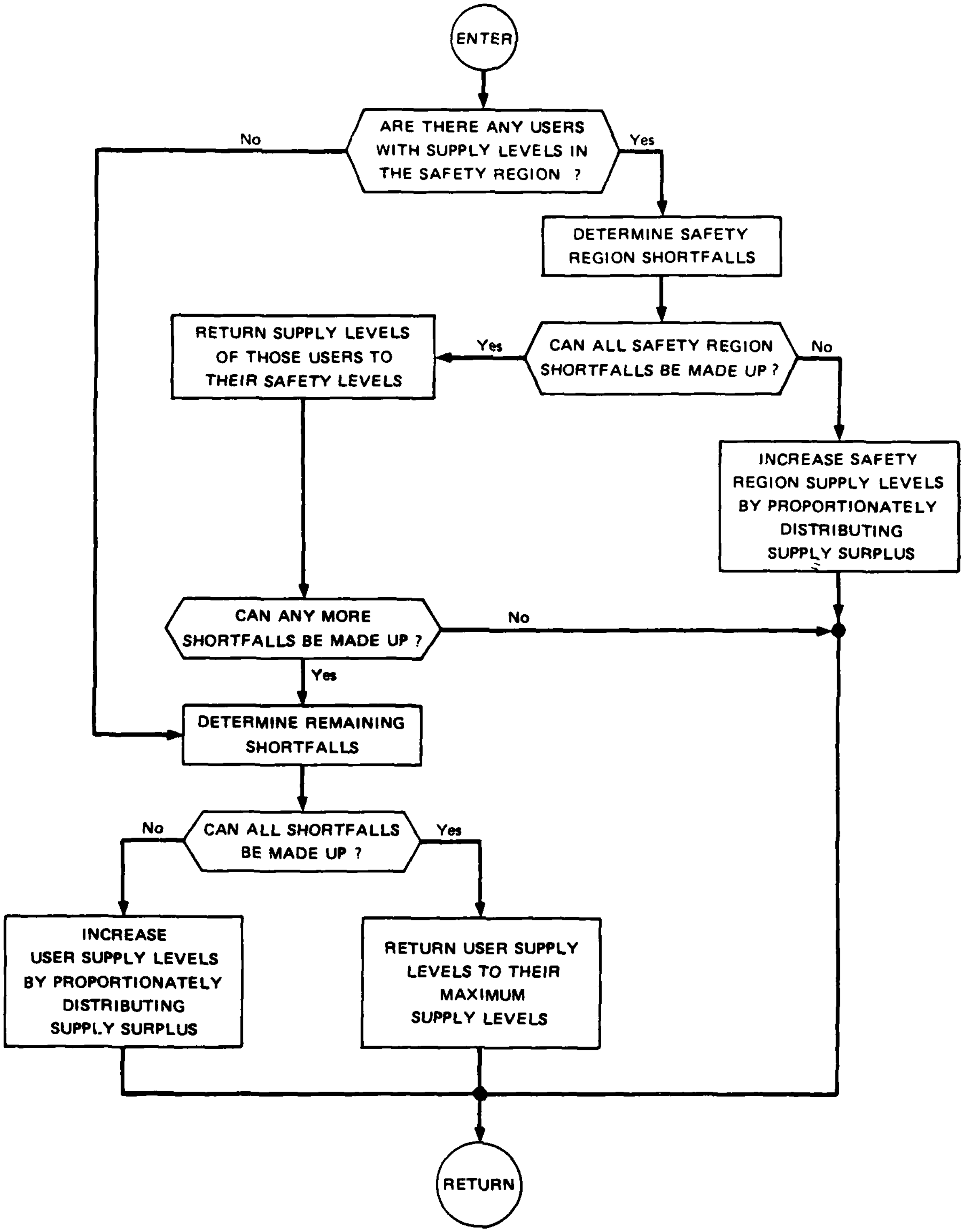

FIGURE IV-14 LOGIC FLOWCHART (SUBROUTINE SHORTFALL)

levels are determined in accordance with the following equation:

$$BL(I,P) = BL(I,P) + \frac{SF(I)}{SSF} \cdot SFM \qquad (IV-104)$$

In this case, the subroutine processing is completed, and a return is made to the main module at the subroutine calling point. If, on the other hand, ($SFM \geq SSF$), then all the safety level shortfalls are made up. That is,

$$BL(I,P) = BSL(I,P) \qquad (IV-105)$$

for all users with $SE(I,P) = 4$, and any remaining surplus to be distributed is determined as follows:

$$SFM = SFM-SSF \qquad (IV-106)$$

If this remaining surplus should equal zero, then the subroutine processing is completed, and a return is made to the main module at the subroutine calling point. Otherwise, the processing continues as if there were initially no users with supply levels in the safety region but with the reduced amount of surplus as determined by Eq. (IV-106) above.

When there are no active users with supply levels in their respective safety regions, the first step is to determine each active user's shortfall as follows:

$$SF(I) = BML(I,P)-BL(I,P) \qquad (IV-107)$$

The total shortfall SSF is then given by

$$SSF = \sum_{I=1}^{NB} SF(I) \qquad (IV-108)$$

where the sum is, of course, taken over only the active users. If the supply surplus is enough to eliminate all active user shortfalls (SFM $\geq$ SSF), then the active user's supply levels are set equal to their maximum supply levels. That is,

$$BL(I,P) = BML(I,P) \qquad \text{(IV-109)}$$

for each active user. Otherwise, the supply surplus is distributed proportionately among the active users in accordance with Eq. (IV-104). This completes the processing of this subroutine, and a return is made to the main module at the subroutine calling point.

C. Sample Problem

The sample problem presented in this section was designed to illustrate the application of the SUPPLY DISTRIBUTION MODULE to the evaluation of a possible supply pipeline operation. The numerical values of the input data are, in general, realistic in terms of present Navy operations. However, some leeway has been taken to allow specific module events to occur. The following discussion considers the scenario description, the associated input data presentation, and a description of the resulting module output data.*

1. Scenario

The scenario assumed for the sample problem considers two Navy task groups deployed in the Indian Ocean Basin. Task Group One (User No. 1) could represent an attack carrier task group, and Task Group Two (User No. 2) could represent an

* The running of this sample problem on a CDC CYBER Series computer consumed 14.3 CPU seconds.

amphibious task group, deployed at some distance from the carrier task group. These two task groups are supplied by a sea-based service group, which could consist of a stores ship (AF), an oiler (AO), and an ammunition ship (AE).

The service group is replenished by MSC or commercial ships sailing from alternative supply sources. The supply of bulk POL is assumed to emanate from a relatively close source, such as Diego Garcia, which is located approximately 800 nmi from the service group. Ammunition, on the other hand, is assumed to be supplied from a remote Navy base, such as Subic Bay in the Phillipines, located at a distance of some 4000 nmi. The remainder of supplies are obtained from a port on the Persian Gulf, such as Bahrain off the coast of Arabia, located at a distance of approximately 1000 nmi.

At the onset, the task groups and the service group are assumed to be stocked at their maximum supply capacity levels and operating under normal peacetime conditions. On the 85th day of deployment, tensions mount in the area, and the carrier task group is forced to increase the tempo of its operations. At the 160th day, the situation has worsened to such an extent that Marines are sent ashore from the amphibious task group, although there is no immediate hostile action. However, 15 days later (Day 175), the Marine forces become engaged in combat operations ashore. After five days of combat, it is assumed that the Air Force has established itself in the area, easing the burden on the carrier task group. The carrier task group, in turn, resorts back to operations commensurate with its peacetime operations. After 290 days, combat operations cease, although the Marine forces remain ashore. One month later (Day 320), the Marine forces withdraw to their sea-based quarters, but they remain in the area until Day 400. At that time, the two task groups and the service group withdraw from the area.

2. Problem Input

The input data for the SUPPLY DISTRIBUTION MODULE representing this scenario are presented in Table IV-2 and IV-3.

Table IV-2

SAMPLE PROBLEM INPUTS
(Initial Conditions)

Input Descriptor	Pipeline 1	Pipeline 2	Pipeline 3
Scheduled Printout Inputs			
Printout interval	30 days	30 days	30 days
Scheduled run duration	400 days	400 days	400 days
Supply Source Inputs			
Pipeline name	BULK POL	AMMUNITION	OTHER SUPPLIES
Cargo carrier capacity	160 kbbl	3400 ST	4500 ST
Cargo carrier speed	20 knots	20 knots	20 knots
Cargo carrier loading rate	450 kbbl/day	4000 ST/day	4000 ST/day
Cargo preparation rate	5000 kbbl/day	2000 ST/day	2000 ST/day
Recycle down time	20 days	20 days	20 days
ISP Inputs			
Storage capacity	100 kbbl	2500 ST	2000 ST
Cargo carrier unloading rate	380 kbbl/day	3000 ST/day	2800 ST/day
Own supply demand rate	1 kbbl/day	0.1 ST/day	3 ST/day
Emergency stores level	40 kbbl	1500 ST	1500 ST
Critical stores level	15 kbbl	10 ST	100 ST
Transit distance between supply source and ISP	800 nmi	4000 nmi	1000 nmi
Order time	2 days	2 days	2 days
Number of Users	2	2	2
User 1 inputs			
Initial demand rate	3 kbbl/day	2 ST/day	25 ST/day
Initial essentiality priority number	0.5	0.5	0.5
Maximum supply level	80 kbbl	100 ST	1500 ST
Safety supply level	50 kbbl	60 ST	750 ST
Critical supply level	30 kbbl	20 ST	250 ST
User 2 inputs			
Initial demand rate	2.5 kbbl/day	3 ST/day	20 ST/day
Initial essentiality priority number	0.5	0.5	0.5
Maximum supply level	90 kbbl	150 ST	1200 ST
Safety supply level	40 kbbl	90 ST	600 ST
Critical supply level	25 kbbl	30 ST	200 ST

ST - Short Tons
kbbl - Thousands of Barrels

Table IV-3

SAMPLE PROBLEM INPUTS
(Contingencies)

Contingency Number	Day of Occurrence	Instigating User Number	User's New Demands			User's New *Essential Priorities*		
			Pipeline 1 (kbbl/day)	Pipeline 2 (ST/day)	Pipeline 3 (ST/day)	Pipeline 1	Pipeline 2	Pipeline 3
1	85	1	18	4	30	0.8	0.8	0.8
2	160	2	10	6	25	0.8	0.8	0.8
3	175	2	40	45	45	1.0	1.0	1.0
4	180	1	3	2	25	0.5	0.5	0.5
5	290	2	10	6	25	0.8	0.8	0.8
6	320	2	2.5	3	20	0.5	0.5	0.5

ST - Short Tons
kbbl - Thousands of Barrels

Table IV-2 presents the input data defining the appropriate supply characteristics of the problem components (geography, supply source, cargo carriers, ISP, and users) and the initial user demand rates and essential priorities. Table IV-3 presents a schedule of the contingency events, indicating the effects on the user demand rates and essential priorities. These inputs are purely hypothetical in nature and in no way reflect present Navy planning factors. Their use is intended only to illustrate the use of the module in evaluating pipeline throughput distributions.

3. Problem Output

For the sample scenario, the most critical pipeline is the one servicing Bulk POL, where both users are required to draw from their safety region supplies shortly after the Marine Corps forces become engaged in combat on Day 175. The other two pipelines (Ammunition and Other Supplies) are stressed somewhat, but never to a degree that the user demands cannot be satisfied. That is, the ISP does have to draw from its emergency supplies for short time periods for each of these two pipelines. However, this is never done to the extent that user demands cannot be satisfied.

In the case of Bulk POL, the situation is more critical. Fig. IV-15 provides a graphical representation of the ISP and user supply levels for Bulk POL during a 35-day period encompassing Day 175. Figs. IV-16 and IV-17 present excerpts of the Event Chronology and Event Sequenced Supply Level tables for this pipeline during this period. Figs. IV-18 and IV-19 respectively, portray the complete Time Sequenced Supply Level table and Supply Rate Variation table for Bulk POL. A complete listing of the module output tables is presented in Fig. IV-20 at the end of this chapter (following Section D.).

Initially, the Bulk POL pipeline has cargo carriers arriving at the ISP every 9.23 days, transferring 60,000 barrels of fuel on each arrival. This cycle continues until the 85th

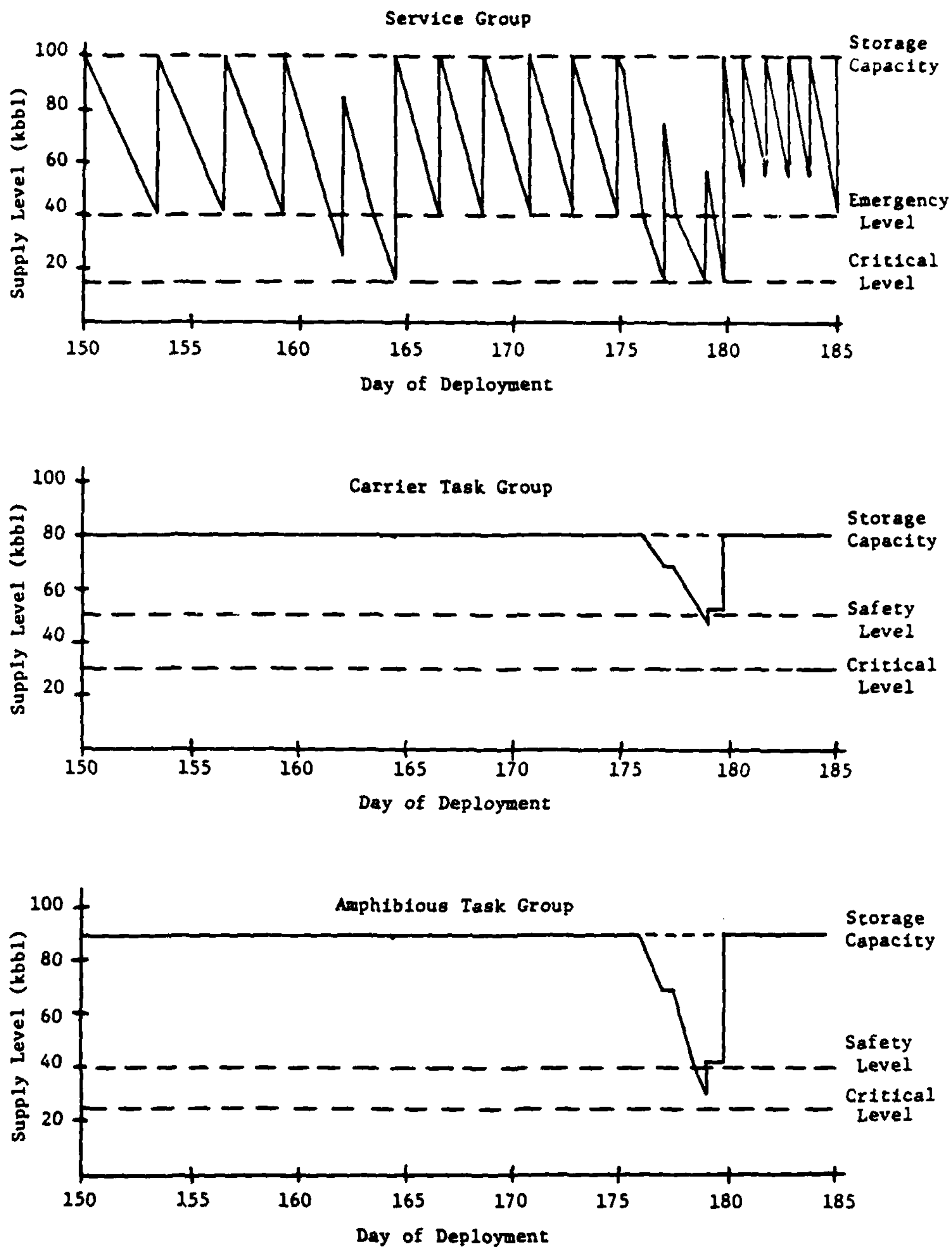

Figure IV-15. BULK POL SUPPLY LEVELS (DAY 150 - DAY 185)

TABLE 1 PIPELINE - BULK POL

EVENT CHRONOLOGY

TIME	EVENT TYPE NUMBER	EVENT DESCRIPTION
150.87	1	CARGO CARRIER ARRIVAL AT ISP
153.66	1	CARGO CARRIER ARRIVAL AT ISP
156.45	1	CARGO CARRIER ARRIVAL AT ISP
159.24	1	CARGO CARRIER ARRIVAL AT ISP
160.00	5	CONTINGENCY EVENT -- USER NUMBER 2
161.51	2	ISP DIPPING INTO EMERGENCY SUPPLIES
162.03	1	CARGO CARRIER ARRIVAL AT ISP
163.56	2	ISP DIPPING INTO EMERGENCY SUPPLIES
164.46	1	CARGO CARRIER ARRIVAL AT ISP
166.54	1	CARGO CARRIER ARRIVAL AT ISP
168.61	1	CARGO CARRIER ARRIVAL AT ISP
170.68	1	CARGO CARRIER ARRIVAL AT ISP
172.75	1	CARGO CARRIER ARRIVAL AT ISP
174.82	1	CARGO CARRIER ARRIVAL AT ISP
175.00	5	CONTINGENCY EVENT -- USER NUMBER 2
175.93	2	ISP DIPPING INTO EMERGENCY SUPPLIES
176.89	1	CARGO CARRIER ARRIVAL AT ISP
177.48	2	ISP DIPPING INTO EMERGENCY SUPPLIES
178.59	3	SUPPLY LEVEL DROPS BELOW SAFETY LEVEL -- USER NUMBER 2
178.71	3	SUPPLY LEVEL DROPS BELOW SAFETY LEVEL -- USER NUMBER 1
178.96	1	CARGO CARRIER ARRIVAL AT ISP
179.23	2	ISP DIPPING INTO EMERGENCY SUPPLIES
179.66	1	CARGO CARRIER ARRIVAL AT ISP
180.00	5	CONTINGENCY EVENT -- USER NUMBER 1
180.67	1	CARGO CARRIER ARRIVAL AT ISP
181.69	1	CARGO CARRIER ARRIVAL AT ISP
182.71	1	CARGO CARRIER ARRIVAL AT ISP
183.73	1	CARGO CARRIER ARRIVAL AT ISP
185.09	1	CARGO CARRIER ARRIVAL AT ISP
186.45	1	CARGO CARRIER ARRIVAL AT ISP
187.82	1	CARGO CARRIER ARRIVAL AT ISP

Figure IV-16

TABLE 2 PIPELINE - BULK POL

EVENT SEQUENCED SUPPLY LEVELS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	USER NUMBER 2
156.45	1	100.00	80.00	90.00
159.24	1	40.00	80.00	90.00
159.24	1	100.00	80.00	90.00
160.00	5	63.72	80.00	90.00
161.51	2	40.00	80.00	90.00
162.03	1	24.75	80.00	90.00
162.03	1	64.75	80.00	90.00
163.56	2	40.00	80.00	90.00
164.48	1	15.00	79.32	89.62
164.48	1	100.00	80.00	90.00
166.54	1	40.00	80.00	90.00
166.54	1	100.00	80.00	90.00
168.61	1	40.00	80.00	90.00
168.61	1	100.00	80.00	90.00
170.68	1	40.00	80.00	90.00
170.68	1	100.00	80.00	90.00
172.75	1	40.00	80.00	90.00
172.75	1	100.00	80.00	90.00
174.82	1	40.00	80.00	90.00
174.82	1	100.00	80.00	90.00
175.00	5	94.78	80.00	90.00
175.93	2	40.00	80.00	90.00
176.69	1	15.00	68.60	69.73
176.89	1	75.00	66.60	69.73
177.46	2	40.00	66.60	69.73
178.59	3	21.29	51.88	40.00
178.71	3	19.19	50.00	36.67
178.96	1	15.00	46.77	29.49
178.96	1	56.26	51.87	43.12
179.23	2	40.00	51.87	43.12
179.66	1	15.00	51.87	43.12
179.66	1	100.00	80.00	90.00
180.00	5	79.78	80.00	90.00
180.00	6	79.78	80.00	90.00
180.67	1	50.11	80.00	90.00
180.67	1	100.00	80.00	90.00
181.69	1	55.25	80.00	90.00
181.69	1	100.00	80.00	90.00
182.71	1	55.25	80.00	90.00
182.71	1	100.00	80.00	90.00
183.73	1	55.25	80.00	90.00
183.73	1	100.00	80.00	90.00

Figure IV-17

TABLE 3 PIPELINE - BULK POL

TIME SEQUENCED SUPPLY LEVELS

TIME	ISP	USER NUMBER 1	2
0.00	100.00	80.00	90.00
30.00	85.00	80.00	90.00
60.00	70.00	80.00	90.00
90.00	88.72	80.00	90.00
120.00	43.72	80.00	90.00
150.00	56.72	80.00	90.00
180.00	79.78	80.00	90.00
210.00	83.91	80.00	90.00
240.00	83.91	80.00	90.00
270.00	63.91	80.00	90.00
300.00	59.43	80.00	90.00
330.00	53.31	80.00	90.00
360.00	98.31	80.00	90.00
390.00	83.31	80.00	90.00
400.00	76.31	80.00	90.00

Figure IV-18

TABLE 4 PIPELINE - BULK POL

SUPPLY RATE VARIATIONS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	USER NUMBER 2
0.00	0	6.50	3.00	2.50
85.00	5	21.50	18.00	2.50
87.21	2	11.03	9.44	0.60
89.48	1	21.50	18.00	2.50
160.00	5	29.00	18.00	10.00
163.58	2	27.82	17.24	9.56
164.48	1	29.00	18.00	10.00
175.00	5	59.00	18.00	40.00
175.93	2	26.03	6.13	18.90
176.89	1	59.00	18.00	40.00
177.48	2	16.94	2.86	13.08
178.71	3	16.94	4.95	10.99
178.96	1	59.00	18.00	40.00
180.00	5	44.00	3.00	40.00
290.00	5	14.00	3.00	10.00
320.00	5	6.50	3.00	2.50
400.00	7	6.50	3.00	2.50

Figure IV-19

day, when the carrier task group (User Number 1) increases its demand from 3,000 barrels per day to 18,000 barrels per day. A new static pipeline operation is then set up, which will have cargo carriers arriving every 2.79 days with 60,000 barrels of fuel. An interim cargo carrier with a full load of fuel is dispatched immediately and will arrive midway through the 89th day. On the 87th day, the ISP begins drawing from its emergency supplies, and the user's supply rates are reduced below their demands. Thus, the users have to draw from their reserves to satisfy their full demands. On arrival of the interim cargo carrier on the 89th day, the ISP supply level has just dropped to its critical levl. The replenishment brings the ISP's supply level up to its maximum storage capacity and also returns the user supply levels to their maximum levels. At this time, the new static pipeline operation begins, and users' demands are once again satisfied by the ISP.

This operation proceeds smoothly until Day 160, when the amphibious task group (User Number 2) increases its demand from 2,500 barrels per day to 10,000 barrels per day. A new static pipeline operation is set up with cargo carrier arrivals scheduled 2.06 days apart. One already-enroute carrier will arrive in two days and an interim cargo carrier is dispatched to arrive two days later. On Day 161, the ISP is forced to draw from its emergency supplies but is able to satisfy the user demands, because the enroute cargo carrier will arrive the next day. When this carrier arrives, the ISP's supply level is increased to a point above its emergency supply level but not up to its maximum storage capacity (because the arriving cargo carrier was loaded in accordance with the previous pipeline operation). On the next day, the ISP again begins to draw from its emergency supplies and, at this time it is unable to satisfy user demands. Thus, the users are again forced to draw from their reserve to maintain their own demand. On the subsequent day, the interim cargo carrier arrives, and all supply levels are returned to their maximums. The static pipeline operation is then implemented.

On Day 175, when combat operations commence, the amphibious task group's demand increases to 40,000 barrels of fuel per day and another pipeline operation is established, which will eventually have cargo carriers arriving at 1.02 day intervals. However, in the interim period of about four and a half days, the pipeline becomes severely stressed. Near the end of the 175th day, the ISP begins drawing on its emergency supplies and must reduce its supply rate so that the users are forced to draw from their reserves. This is alleviated late the next day, when a previously enroute cargo carrier arrives. The ISP supply level rises above its emergency level, but not to its storage capacity. User demands can be met, but no surplus is available to reduce user shortfalls.

At the middle of the next day (Day 177), the ISP once again begins drawing from emergency supplies, and user demands cannot be satisfied. On the next day, both users' supply levels drop below their safety levels. Later that day, when the carrier task group's supply level is about 16,000 barrels above its critical supply level, and the amphibious task group's supply level is only about 4,500 barrels above the critical level, another previously enroute cargo carrier arrives. This allows the ISP's supply level to rise above the emergency supply level. Because an interim cargo carrier with a full cargo load is scheduled to arrive the next day, the ISP is able to make up some of the user shortfalls and still satisfy their demands, even when its supply level drops below its emergency supply level early on the next day (Day 179). The arrival of the interim cargo carrier later that day allows all supply levels to be returned to their maximums. From this point on, the pipeline operation runs smoothly.

The remaining contingency events represent decreases in user demands. These only cause a revision in the cargo carrier scheduling, with user demands always being satisfied. On the 400th day, the task groups and the service group withdraw, and the pipeline operations are cancelled.

D. Module Limitations

The SUPPLY DISTRIBUTION MODULE described in this chapter represents an initial construct of an analytical tool designed to provide a basis for evaluating the distribution of supplies to operating forces engaged in a theater war scenario within the context of BALFRAM. Although the module was designed as an adjunct to BALFRAM, it can stand alone as a useful tool in other supply distribution analyses. The module design was constrained by the level-of-effort limitations of the present research contract. Thus, a number of desirable features that would enhance the module's usefulness were not included. In this chapter, the more significant of these features are identified. These could be included in a future expansion of the module.

1. Multiple ISPs Per Pipeline

The present module represents pipelines designed to service a single ISP. In reality, it is more likely that pipelines would be set up to service more than one ISP, especially in situations where ISP and user supply capacity limitations result in cargo carrier shipments with cargo loads much less than each carrier's capacity. Thus, one area for module expansion is to allow pipelines to service more than one ISP.

2. ISP and User Mobility

In the present module, it is assumed that the ISP and its associated users remain at fixed stations or locations. For naval operations especially, the users (task groups) are highly likely to move to an alternative station during a given at-sea deployment. This implies, in many cases, that the ISP (service group) providing support to the users would also move to alternate stations to maintain proximity with its user units. These movements could be considered as another category of contingency events within the structure of the module. Expansion

of the module to include this feature would enhance its usefulness as a supply distribution system evaluation tool.

3. ISP-to-User Pipelines

The present module assumes that there is a continuous flow of supplies from the ISP to its associated users, with no capacity limitations on this portion of the pipeline. Actually, the ISP-to-User pipelines are constrained in several ways. There will be limitations on the number and capacities of intermediary cargo carriers (ISP-to-User) such as a truck convoys or amphibious supply ships servicing land-based Marine forces from a Mobile Logistic Support Group. For sea-based users and service groups, a user may leave its station and rendevous with the ships of the service group, or vice versa. In the former case, the user will be required to be off-station some of the time, and this will degrade the user's on-station readiness. In the latter case, an ISP supply ship will be tied up servicing one user and unavailable, at the time, to service another user. These limitations could have a significant effect on the effectiveness of the pipeline operations. Thus, it would be fruitful to expand the module to accommodate these restrictions.

4. Emergency Pipelines

The present module does not provide for the use of emergency pipelines that may be required when the normal pipeline is in a period of stress. Emergency pipelines could emanate from alternative supply sources and/or, they could utilize faster modes of transportation, such as aircraft or fast supply ships, to speed up the flow of supplies to the ISP. Inclusion of this feature in the module would increase its credibility and enhance its usefulness.

5. Cargo Carrier Limitation

In the present module, it is assumed that there are always enough cargo carriers available to the supply source to

meet the requirements of a pipeline operation. In many cases, this may not be true. Thus, a pipeline operation would have to be modified to accommodate the cargo carrier limitations. Quite possibly, more than one pipeline for a given class of supplies would be needed to support an ISP. Inclusion of cargo carrier limitations in the module would provide a more useful and realistic tool for analyzing supply distribution effectiveness.

6. BALFRAM Integration

The module, as presently designed, is a separate adjunct to BALFRAM. The main drawback is that the module is not reactive, in realtime, to user demands that would vary in a BALFRAM scenario. Joint usage of BALFRAM and the module would first require a BALFRAM run to establish the requirements imposed on the pipelines providing supplies to the theater area. Then a set of module runs would be required to iterate on a solution defining the pipeline characteristics necessary to meet these requirements. A worthwhile module modification would be to provide for concurrent integrated operation with BALFRAM, where the necessary pipeline adjustments can be established as BALFRAM supply requirements change.

TABLE 1 PIPELINE - [illegible] POL

EVENT CHRONOLOGY

TIME	EVENT TYPE NUMBER	EVENT DESCRIPTION
9.23	1	CARGO CARRIER ARRIVAL AT ISP
18.46	1	CARGO CARRIER ARRIVAL AT ISP
27.69	1	CARGO CARRIER ARRIVAL AT ISP
36.92	1	CARGO CARRIER ARRIVAL AT ISP
46.15	1	CARGO CARRIER ARRIVAL AT ISP
55.38	1	CARGO CARRIER ARRIVAL AT ISP
64.62	1	CARGO CARRIER ARRIVAL AT ISP
73.85	1	CARGO CARRIER ARRIVAL AT ISP
83.08	1	CARGO CARRIER ARRIVAL AT ISP
85.00	5	CONTINGENCY EVENT -- USER NUMBER 1
87.21	2	ISP DIPPING INTO EMERGENCY SUPPLIES
89.48	1	CARGO CARRIER ARRIVAL AT ISP
92.27	1	CARGO CARRIER ARRIVAL AT ISP
95.06	1	CARGO CARRIER ARRIVAL AT ISP
97.85	1	CARGO CARRIER ARRIVAL AT ISP
100.64	1	CARGO CARRIER ARRIVAL AT ISP
103.43	1	CARGO CARRIER ARRIVAL AT ISP
106.22	1	CARGO CARRIER ARRIVAL AT ISP
109.01	1	CARGO CARRIER ARRIVAL AT ISP
111.80	1	CARGO CARRIER ARRIVAL AT ISP
114.59	1	CARGO CARRIER ARRIVAL AT ISP
117.38	1	CARGO CARRIER ARRIVAL AT ISP
120.17	1	CARGO CARRIER ARRIVAL AT ISP
122.96	1	CARGO CARRIER ARRIVAL AT ISP
125.75	1	CARGO CARRIER ARRIVAL AT ISP
128.55	1	CARGO CARRIER ARRIVAL AT ISP
131.34	1	CARGO CARRIER ARRIVAL AT ISP
134.13	1	CARGO CARRIER ARRIVAL AT ISP
136.92	1	CARGO CARRIER ARRIVAL AT ISP
139.71	1	CARGO CARRIER ARRIVAL AT ISP
142.50	1	CARGO CARRIER ARRIVAL AT ISP
145.29	1	CARGO CARRIER ARRIVAL AT ISP
148.08	1	CARGO CARRIER ARRIVAL AT ISP
150.87	1	CARGO CARRIER ARRIVAL AT ISP
153.66	1	CARGO CARRIER ARRIVAL AT ISP
156.45	1	CARGO CARRIER ARRIVAL AT ISP
159.24	:	CARGO CARRIER ARRIVAL AT ISP
160.00	5	CONTINGENCY EVENT -- USER NUMBER 2
161.51	2	ISP DIPPING INTO EMERGENCY SUPPLIES
162.03	1	CARGO CARRIER ARRIVAL AT ISP
163.58	2	ISP DIPPING INTO EMERGENCY SUPPLIES
164.48	1	CARGO CARRIER ARRIVAL AT ISP
166.54	1	CARGO CARRIER ARRIVAL AT ISP
168.61	1	CARGO CARRIER ARRIVAL AT ISP
170.68	1	CARGO CARRIER ARRIVAL AT ISP
172.75	1	CARGO CARRIER ARRIVAL AT ISP
174.82	1	CARGO CARRIER ARRIVAL AT ISP
175.00	5	CONTINGENCY EVENT -- USER NUMBER 2

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES

175.93	2	ISP DIPPING INTO EMERGENCY SUPPLIES
176.89	1	CARGO CARRIER ARRIVAL AT ISP
177.48	2	ISP DIPPING INTO EMERGENCY SUPPLIES
178.59	3	SUPPLY LEVEL DROPS BELOW SAFETY LEVEL -- USER NUMBER 2
178.71	3	SUPPLY LEVEL DROPS BELOW SAFETY LEVEL -- USER NUMBER 1
178.96	1	CARGO CARRIER ARRIVAL AT ISP
179.23	2	ISP DIPPING INTO EMERGENCY SUPPLIES
179.66	1	CARGO CARRIER ARRIVAL AT ISP
180.00	5	CONTINGENCY EVENT -- USER NUMBER 1
180.67	1	CARGO CARRIER ARRIVAL AT ISP
181.69	1	CARGO CARRIER ARRIVAL AT ISP
182.71	1	CARGO CARRIER ARRIVAL AT ISP
183.73	1	CARGO CARRIER ARRIVAL AT ISP
185.09	1	CARGO CARRIER ARRIVAL AT ISP
186.45	1	CARGO CARRIER ARRIVAL AT ISP
187.82	1	CARGO CARRIER ARRIVAL AT ISP
189.18	1	CARGO CARRIER ARRIVAL AT ISP
190.54	1	CARGO CARRIER ARRIVAL AT ISP
191.91	1	CARGO CARRIER ARRIVAL AT ISP
193.27	1	CARGO CARRIER ARRIVAL AT ISP
194.63	1	CARGO CARRIER ARRIVAL AT ISP
196.00	1	CARGO CARRIER ARRIVAL AT ISP
197.36	1	CARGO CARRIER ARRIVAL AT ISP
198.73	1	CARGO CARRIER ARRIVAL AT ISP
200.09	1	CARGO CARRIER ARRIVAL AT ISP
201.45	1	CARGO CARRIER ARRIVAL AT ISP
202.82	1	CARGO CARRIER ARRIVAL AT ISP
204.18	1	CARGO CARRIER ARRIVAL AT ISP
205.54	1	CARGO CARRIER ARRIVAL AT ISP
206.91	1	CARGO CARRIER ARRIVAL AT ISP
208.27	1	CARGO CARRIER ARRIVAL AT ISP
209.63	1	CARGO CARRIER ARRIVAL AT ISP
211.00	1	CARGO CARRIER ARRIVAL AT ISP
212.36	1	CARGO CARRIER ARRIVAL AT ISP
213.73	1	CARGO CARRIER ARRIVAL AT ISP
215.09	1	CARGO CARRIER ARRIVAL AT ISP
216.45	1	CARGO CARRIER ARRIVAL AT ISP
217.82	1	CARGO CARRIER ARRIVAL AT ISP
219.18	1	CARGO CARRIER ARRIVAL AT ISP
220.54	1	CARGO CARRIER ARRIVAL AT ISP
221.91	1	CARGO CARRIER ARRIVAL AT ISP
223.27	1	CARGO CARRIER ARRIVAL AT ISP
224.63	1	CARGO CARRIER ARRIVAL AT ISP
226.00	1	CARGO CARRIER ARRIVAL AT ISP
227.36	1	CARGO CARRIER ARRIVAL AT ISP
228.73	1	CARGO CARRIER ARRIVAL AT ISP
230.09	1	CARGO CARRIER ARRIVAL AT ISP
231.45	1	CARGO CARRIER ARRIVAL AT ISP
232.82	1	CARGO CARRIER ARRIVAL AT ISP
234.18	1	CARGO CARRIER ARRIVAL AT ISP
235.54	1	CARGO CARRIER ARRIVAL AT ISP
236.91	1	CARGO CARRIER ARRIVAL AT ISP
238.27	1	CARGO CARRIER ARRIVAL AT ISP
239.63	1	CARGO CARRIER ARRIVAL AT ISP
241.00	1	CARGO CARRIER ARRIVAL AT ISP
242.36	1	CARGO CARRIER ARRIVAL AT ISP
243.73	1	CARGO CARRIER ARRIVAL AT ISP
245.09	1	CARGO CARRIER ARRIVAL AT ISP
246.45	1	CARGO CARRIER ARRIVAL AT ISP
247.82	1	CARGO CARRIER ARRIVAL AT ISP
249.18	1	CARGO CARRIER ARRIVAL AT ISP

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

250.54	1	CARGO CARRIER ARRIVAL AT ISP
251.91	1	CARGO CARRIER ARRIVAL AT ISP
253.27	1	CARGO CARRIER ARRIVAL AT ISP
254.63	1	CARGO CARRIER ARRIVAL AT ISP
256.00	1	CARGO CARRIER ARRIVAL AT ISP
257.36	1	CARGO CARRIER ARRIVAL AT ISP
258.73	1	CARGO CARRIER ARRIVAL AT ISP
260.09	1	CARGO CARRIER ARRIVAL AT ISP
261.45	1	CARGO CARRIER ARRIVAL AT ISP
262.82	1	CARGO CARRIER ARRIVAL AT ISP
264.18	1	CARGO CARRIER ARRIVAL AT ISP
265.54	1	CARGO CARRIER ARRIVAL AT ISP
266.91	1	CARGO CARRIER ARRIVAL AT ISP
268.27	1	CARGO CARRIER ARRIVAL AT ISP
269.63	1	CARGO CARRIER ARRIVAL AT ISP
271.00	1	CARGO CARRIER ARRIVAL AT ISP
272.36	1	CARGO CARRIER ARRIVAL AT ISP
273.73	1	CARGO CARRIER ARRIVAL AT ISP
275.09	1	CARGO CARRIER ARRIVAL AT ISP
276.45	1	CARGO CARRIER ARRIVAL AT ISP
277.82	1	CARGO CARRIER ARRIVAL AT ISP
279.18	1	CARGO CARRIER ARRIVAL AT ISP
280.54	1	CARGO CARRIER ARRIVAL AT ISP
281.91	1	CARGO CARRIER ARRIVAL AT ISP
283.27	1	CARGO CARRIER ARRIVAL AT ISP
284.63	1	CARGO CARRIER ARRIVAL AT ISP
286.00	1	CARGO CARRIER ARRIVAL AT ISP
287.36	1	CARGO CARRIER ARRIVAL AT ISP
288.73	1	CARGO CARRIER ARRIVAL AT ISP
290.00	5	CONTINGENCY EVENT -- USER NUMBER 2
290.09	1	CARGO CARRIER ARRIVAL AT ISP
291.45	1	CARGO CARRIER ARRIVAL AT ISP
292.82	1	CARGO CARRIER ARRIVAL AT ISP
297.10	1	CARGO CARRIER ARRIVAL AT ISP
301.39	2	ISP DIPPING INTO EMERGENCY SUPPLIES
301.39	1	CARGO CARRIER ARRIVAL AT ISP
305.67	1	CARGO CARRIER ARRIVAL AT ISP
309.96	1	CARGO CARRIER ARRIVAL AT ISP
314.24	1	CARGO CARRIER ARRIVAL AT ISP
318.53	1	CARGO CARRIER ARRIVAL AT ISP
320.00	5	CONTINGENCY EVENT -- USER NUMBER 2
322.82	1	CARGO CARRIER ARRIVAL AT ISP
332.05	1	CARGO CARRIER ARRIVAL AT ISP
341.28	1	CARGO CARRIER ARRIVAL AT ISP
350.51	1	CARGO CARRIER ARRIVAL AT ISP
359.74	1	CARGO CARRIER ARRIVAL AT ISP
368.97	1	CARGO CARRIER ARRIVAL AT ISP
378.20	1	CARGO CARRIER ARRIVAL AT ISP
387.43	1	CARGO CARRIER ARRIVAL AT ISP
396.66	1	CARGO CARRIER ARRIVAL AT ISP
400.00	7	RUN TERMINATED BEFORE LAST CONTINGENCY HAS BEEN STABILIZED

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 2 PIPELINE - BULK POL

EVENT SEQUENCED SUPPLY LEVELS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	2	3	4	5	6	7	8	9	10
0.00	0	100.00	80.00	90.00								
9.23	1	40.00	80.00	90.00								
9.23	1	100.00	80.00	90.00								
18.46	1	40.00	80.00	90.00								
18.46	1	100.00	80.00	90.00								
27.69	1	40.00	80.00	90.00								
27.69	1	100.00	80.00	90.00								
30.00	6	85.00	80.00	90.00								
36.92	1	40.00	80.00	90.00								
36.92	1	100.00	80.00	90.00								
46.15	1	40.00	80.00	90.00								
46.15	1	100.00	80.00	90.00								
55.38	1	40.00	80.00	90.00								
55.38	1	100.00	80.00	90.00								
60.00	6	70.00	80.00	90.00								
64.62	1	40.00	80.00	90.00								
64.62	1	100.00	80.00	90.00								
73.85	1	40.00	80.00	90.00								
73.85	1	100.00	80.00	90.00								
83.08	1	40.00	80.00	90.00								
83.08	1	100.00	80.00	90.00								
85.00	5	87.50	80.00	90.00								
87.21	2	40.00	80.00	90.00								
89.48	1	15.00	60.59	85.69								
89.48	1	100.00	80.00	90.00								
90.00	6	88.72	80.00	90.00								
92.27	1	40.00	80.00	90.00								
92.27	1	100.00	80.00	90.00								
95.06	1	40.00	80.00	90.00								
95.06	1	100.00	80.00	90.00								
97.85	1	40.00	80.00	90.00								
97.85	1	100.00	80.00	90.00								
100.64	1	40.00	80.00	90.00								
100.64	1	100.00	80.00	90.00								
103.43	1	40.00	80.00	90.00								
103.43	1	100.00	80.00	90.00								
106.22	1	40.00	80.00	90.00								
106.22	1	100.00	80.00	90.00								
109.01	1	40.00	80.00	90.00								
109.01	1	100.00	80.00	90.00								
111.80	1	40.00	80.00	90.00								
111.80	1	100.00	80.00	90.00								
114.59	1	40.00	80.00	90.00								
114.59	1	100.00	80.00	90.00								
117.38	1	40.00	80.00	90.00								
117.38	1	100.00	80.00	90.00								
120.00	6	13.72	80.00	90.00								
120.17	1	40.00	80.00	90.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

120.17	1	100.00	80.00	90.00
122.96	1	40.00	80.00	90.00
122.96	1	100.00	80.00	90.00
125.75	1	40.00	80.00	90.00
125.75	1	100.00	80.00	90.00
128.55	1	40.00	80.00	90.00
128.55	1	100.00	80.00	90.00
131.34	1	40.00	80.00	90.00
131.34	1	100.00	80.00	90.00
134.13	1	40.00	80.00	90.00
134.13	1	100.00	80.00	90.00
136.92	1	40.00	80.00	90.00
136.92	1	100.00	80.00	90.00
139.71	1	40.00	80.00	90.00
139.71	1	100.00	80.00	90.00
142.50	1	40.00	80.00	90.00
142.50	1	100.00	80.00	90.00
145.29	1	40.00	80.00	90.00
145.29	1	100.00	80.00	90.00
148.08	1	40.00	80.00	90.00
148.08	1	100.00	80.00	90.00
150.00	6	58.72	80.00	90.00
150.87	1	40.00	80.00	90.00
150.87	1	100.00	80.00	90.00
153.66	1	40.00	80.00	90.00
153.66	1	100.00	80.00	90.00
156.45	1	40.00	80.00	90.00
156.45	1	100.00	80.00	90.00
159.24	1	40.00	80.00	90.00
159.24	1	100.00	80.00	90.00
160.00	5	83.72	80.00	90.00
161.51	2	40.00	80.00	90.00
162.03	1	24.75	80.00	90.00
162.03	1	84.75	80.00	90.00
163.58	2	40.00	80.00	90.00
164.48	1	15.00	79.32	89.62
164.48	1	100.00	80.00	90.00
166.54	1	40.00	80.00	90.00
166.54	1	100.00	80.00	90.00
168.61	1	40.00	80.00	90.00
168.61	1	100.00	80.00	90.00
170.68	1	40.00	80.00	90.00
170.68	1	100.00	80.00	90.00
172.75	1	40.00	80.00	90.00
172.75	1	100.00	80.00	90.00
174.62	1	40.00	80.00	90.00
174.62	1	100.00	80.00	90.00
175.00	5	94.78	90.00	90.00
175.93	2	40.00	80.00	90.00
176.89	1	15.00	68.60	69.73
176.89	1	75.00	68.60	69.73
177.48	2	40.00	68.60	69.73
178.59	3	21.29	51.88	40.00
178.71	3	19.19	50.00	36.67
178.96	1	15.00	46.77	29.49
178.96	1	56.26	51.87	43.12
179.23	2	40.00	51.87	43.12
179.66	1	15.00	51.87	43.12
179.66	1	100.00	80.00	90.00
180.00	5	79.76	[illegible]	90.00
180.00	6	79.76	80.00	90.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

180.67	1	50.11	80.00	90.00
180.67	1	100.00	80.00	90.00
181.69	1	55.25	80.00	90.00
181.69	1	100.00	80.00	90.00
182.71	1	55.25	80.00	90.00
182.71	1	100.00	80.00	90.00
183.73	1	55.25	80.00	90.00
183.73	1	100.00	80.00	90.00
185.09	1	40.00	80.00	90.00
185.09	1	100.00	80.00	90.00
186.45	1	40.00	80.00	90.00
186.45	1	100.00	80.00	90.00
187.82	1	40.00	80.00	90.00
187.82	1	100.00	80.00	90.00
189.18	1	40.00	80.00	90.00
189.18	1	100.00	80.00	90.00
190.54	1	40.00	80.00	90.00
190.54	1	100.00	80.00	90.00
191.91	1	40.00	80.00	90.00
191.91	1	100.00	80.00	90.00
193.27	1	40.00	80.00	90.00
193.27	1	100.00	80.00	90.00
194.63	1	40.00	80.00	90.00
194.63	1	100.00	80.00	90.00
196.00	1	40.00	80.00	90.00
196.00	1	100.00	80.00	90.00
197.36	1	40.00	80.00	90.00
197.36	1	100.00	80.00	90.00
198.73	1	40.00	80.00	90.00
198.73	1	100.00	80.00	90.00
200.09	1	40.00	80.00	90.00
200.09	1	100.00	80.00	90.00
201.45	1	40.00	80.00	90.00
201.45	1	100.00	80.00	90.00
202.82	1	40.00	80.00	90.00
202.82	1	100.00	80.00	90.00
204.18	1	40.00	80.00	90.00
204.18	1	100.00	80.00	90.00
205.54	1	40.00	80.00	90.00
205.54	1	100.00	80.00	90.00
206.91	1	40.00	80.00	90.00
206.91	1	100.00	80.00	90.00
208.27	1	40.00	80.00	90.00
208.27	1	100.00	80.00	90.00
209.63	1	40.00	80.00	90.00
209.63	1	100.00	80.00	90.00
210.00	6	83.91	80.00	90.00
211.00	1	40.00	80.00	90.00
211.00	1	100.00	80.00	90.00
212.36	1	40.00	80.00	90.00
212.36	1	100.00	80.00	90.00
213.73	1	40.00	80.00	90.00
213.73	1	100.00	80.00	90.00
215.09	1	40.00	80.00	90.00
215.09	1	100.00	80.00	90.00
216.45	1	40.00	80.00	90.00
216.45	1	100.00	80.00	90.00
217.82	1	40.00	80.00	90.00
217.82	1	100.00	80.00	90.00
219.18	1	40.00	80.00	90.00
219.18	1	100.00	80.00	90.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

220.54	1	40.00	80.00	90.00
220.54	1	100.00	80.00	90.00
221.91	1	40.00	80.00	90.00
221.91	1	100.00	80.00	90.00
223.27	1	40.00	80.00	90.00
223.27	1	100.00	80.00	90.00
224.63	1	40.00	80.00	90.00
224.63	1	100.00	80.00	90.00
226.00	1	40.00	80.00	90.00
226.00	1	100.00	80.00	90.00
227.36	1	40.00	80.00	90.00
227.36	1	100.00	80.00	90.00
228.73	1	40.00	80.00	90.00
228.73	1	100.00	80.00	90.00
230.09	1	40.00	80.00	90.00
230.09	1	100.00	80.00	90.00
231.45	1	40.00	80.00	90.00
231.45	1	100.00	80.00	90.00
232.82	1	40.00	80.00	90.00
232.82	1	100.00	80.00	90.00
234.18	1	40.00	80.00	90.00
234.18	1	100.00	80.00	90.00
235.54	1	40.00	80.00	90.00
235.54	1	100.00	80.00	90.00
236.91	1	40.00	80.00	90.00
236.91	1	100.00	80.00	90.00
238.27	1	40.00	80.00	90.00
238.27	1	100.00	80.00	90.00
239.63	1	40.00	80.00	90.00
239.63	1	100.00	80.00	90.00
240.00	6	83.91	60.00	90.00
241.00	1	40.00	80.00	90.00
241.00	1	100.00	80.00	90.00
242.36	1	40.00	80.00	90.00
242.36	1	100.00	80.00	90.00
243.73	1	40.00	80.00	90.00
243.73	1	100.00	80.00	90.00
245.09	1	40.00	80.00	90.00
245.09	1	100.00	80.00	90.00
246.45	1	40.00	80.00	90.00
246.45	1	100.00	80.00	90.00
247.82	1	40.00	80.00	90.00
247.82	1	100.00	80.00	90.00
249.18	1	40.01	80.00	90.00
249.18	1	100.01	80.00	90.00
250.54	1	40.01	80.00	90.00
250.54	1	100.01	80.00	90.00
251.91	1	40.01	80.00	90.00
251.91	1	100.01	80.00	90.00
253.27	1	40.01	80.00	90.00
253.27	1	100.01	80.00	90.00
254.63	1	40.01	80.00	90.00
254.63	1	100.01	80.00	90.00
256.00	1	40.01	80.00	90.00
256.00	1	100.01	80.00	90.00
257.36	1	40.01	80.00	90.00
257.36	1	100.01	80.00	90.00
258.73	1	40.01	80.00	90.00
258.73	1	100.01	80.00	90.00
260.09	1	40.01	80.00	90.00
260.09	1	100.01	80.00	90.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

261.45	1	40.00	80.00	90.00
261.45	1	100.00	80.00	90.00
262.62	1	40.00	80.00	90.00
262.62	1	100.00	80.00	90.00
264.18	1	40.00	80.00	90.00
264.18	1	100.00	80.00	90.00
265.54	1	40.00	80.00	90.00
265.54	1	100.00	80.00	90.00
266.91	1	40.00	80.00	90.00
266.91	1	100.00	80.00	90.00
268.27	1	40.00	80.00	90.00
268.27	1	100.00	80.00	90.00
269.63	1	40.00	80.00	90.00
269.63	1	100.00	80.00	90.00
270.00	6	83.91	80.00	90.00
271.00	1	40.00	80.00	90.00
271.00	1	100.00	80.00	90.00
272.36	1	40.00	80.00	90.00
272.36	1	100.00	80.00	90.00
273.73	1	40.00	80.00	90.00
273.73	1	100.00	80.00	90.00
275.09	1	40.00	80.00	90.00
275.09	1	100.00	80.00	90.00
276.45	1	40.00	80.00	90.00
276.45	1	100.00	80.00	90.00
277.82	1	40.00	80.00	90.00
277.82	1	100.00	80.00	90.00
279.18	1	40.00	80.00	90.00
279.18	1	100.00	80.00	90.00
280.54	1	40.00	80.00	90.00
280.54	1	100.00	80.00	90.00
281.91	1	40.00	80.00	90.00
281.91	1	100.00	80.00	90.00
283.27	1	40.00	80.00	90.00
283.27	1	100.00	80.00	90.00
284.63	1	40.00	80.00	90.00
284.63	1	100.00	80.00	90.00
286.00	1	40.00	80.00	90.00
286.00	1	100.00	80.00	90.00
287.36	1	40.00	80.00	90.00
287.36	1	100.00	80.00	90.00
288.73	1	39.99	80.00	90.00
288.73	1	99.99	80.00	90.00
290.00	5	43.91	80.00	90.00
290.09	1	42.00	80.00	90.00
290.09	1	100.00	80.00	90.00
291.45	1	80.91	80.00	90.00
291.45	1	100.00	80.00	90.00
292.82	1	80.91	80.00	90.00
292.82	1	100.00	80.00	90.00
297.10	1	40.00	80.00	90.00
297.10	1	100.00	80.00	90.00
300.00	6	57.43	80.00	90.00
301.39	2	40.00	80.00	90.00
301.39	1	40.00	80.00	90.00
301.39	1	100.00	80.00	90.00
305.67	1	40.00	80.00	90.00
305.67	1	100.00	80.00	90.00
309.96	1	40.00	80.00	90.00
309.96	1	100.00	80.00	90.00
314.24	1	40.00	80.00	90.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

314.24	1	100.00	80.00	90.00
318.53	1	40.00	80.00	90.00
318.53	1	100.00	80.00	90.00
320.00	5	79.43	80.00	90.00
322.82	1	61.12	80.00	90.00
322.82	1	100.00	80.00	90.00
330.00	6	53.31	80.00	90.00
332.05	1	40.00	80.00	90.00
332.05	1	100.00	80.00	90.00
341.26	1	40.00	80.00	90.00
341.26	1	100.00	80.00	90.00
350.51	1	40.00	80.00	90.00
350.51	1	100.00	80.00	90.00
359.74	1	40.00	80.00	90.00
359.74	1	100.00	80.00	90.00
360.00	6	98.31	80.00	90.00
368.97	1	40.00	80.00	90.00
368.97	1	100.00	80.00	90.00
378.20	1	40.00	80.00	90.00
378.20	1	100.00	80.00	90.00
387.43	1	40.00	80.00	90.00
387.43	1	100.00	80.00	90.00
390.00	6	83.31	80.00	90.00
396.66	1	40.00	80.00	90.00
396.66	1	100.00	80.00	90.00
400.00	7	78.31	80.00	90.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 3 PIPELINE - BULK POL

TIME SEQUENCED SUPPLY LEVELS

		USER NUMBER									
TIME	ISP	1	2	3	4	5	6	7	8	9	10
0.00	100.00	80.00	90.00								
30.00	85.00	80.00	90.00								
60.00	70.00	80.00	90.00								
90.00	88.74	80.00	90.00								
120.00	43.74	90.00	90.00								
150.00	58.72	80.00	90.00								
180.00	79.78	80.00	90.00								
210.00	83.91	80.00	90.00								
240.00	83.91	80.00	90.00								
270.00	83.91	80.00	90.00								
300.00	59.43	80.00	90.00								
330.00	53.31	80.00	90.00								
360.00	98.31	80.00	90.00								
390.00	85.31	80.00	90.00								
400.00	78.31	80.00	90.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 4 PIPELINE - BULK POL

SUPPLY RATE VARIATIONS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	2	3	4	5	6	7	8	9	10
0.00	0	6.50	3.00	2.50								
85.00	5	21.50	18.00	2.50								
87.21	2	11.03	9.44	0.60								
89.48	1	21.50	18.00	2.50								
160.00	5	29.00	18.00	10.00								
163.58	2	27.82	17.24	9.58								
164.48	1	29.00	18.00	10.00								
175.00	5	59.00	18.00	40.00								
175.93	2	26.03	6.13	18.90								
176.89	1	59.00	18.00	40.00								
177.48	2	16.94	2.86	13.08								
178.71	3	16.94	4.95	10.99								
178.96	1	59.00	18.00	40.00								
180.00	5	44.00	3.00	40.00								
290.00	5	14.00	3.00	10.00								
320.00	5	6.50	3.00	2.50								
400.00	7	6.50	3.00	2.50								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 1 PIPELINE - AMMUNITION

EVENT CHRONOLOGY

TIME	EVENT TYPE NUMBER	EVENT DESCRIPTION
85.00	5	CONTINGENCY EVENT -- USER NUMBER 1
160.00	5	CONTINGENCY EVENT -- USER NUMBER 2
163.37	2	ISP DIPPING INTO EMERGENCY SUPPLIES
164.79	1	CARGO CARRIER ARRIVAL AT ISP
175.00	5	CONTINGENCY EVENT -- USER NUMBER 2
180.00	5	CONTINGENCY EVENT -- USER NUMBER 1
193.52	1	CARGO CARRIER ARRIVAL AT ISP
214.76	2	ISP DIPPING INTO EMERGENCY SUPPLIES
214.76	1	CARGO CARRIER ARRIVAL AT ISP
235.99	1	CARGO CARRIER ARRIVAL AT ISP
257.22	1	CARGO CARRIER ARRIVAL AT ISP
278.45	1	CARGO CARRIER ARRIVAL AT ISP
290.00	5	CONTINGENCY EVENT -- USER NUMBER 2
299.68	1	CARGO CARRIER ARRIVAL AT ISP
320.00	5	CONTINGENCY EVENT -- USER NUMBER 2
400.00	7	RUN TERMINATED BEFORE LAST CONTINGENCY HAS BEEN STABILIZED

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 2 PIPELINE - AMMUNITION

EVENT SEQUENCED SUPPLY LEVELS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	2	3	4	5	6	7	8	9	10
0.00	0	2500.00	100.00	150.00								
30.00	6	2347.00	100.00	150.00								
60.00	6	2194.00	100.00	150.00								
85.00	5	2066.50	100.00	150.00								
90.00	6	2031.00	100.00	150.00								
120.00	6	1818.00	100.00	150.00								
150.00	6	1605.00	100.00	150.00								
160.00	5	1534.00	100.00	150.00								
163.37	2	1500.00	100.00	150.00								
164.79	1	1485.63	100.00	150.00								
164.77	1	2485.63	100.00	150.00								
175.00	5	2382.50	100.00	150.00								
180.00	5	2137.00	100.00	150.00								
180.00	6	2137.00	100.00	150.00								
193.52	1	1500.00	100.00	150.00								
193.52	1	2500.00	100.00	150.00								
210.00	6	1724.00	100.00	150.00								
214.76	2	1500.00	100.00	150.00								
214.76	1	1500.00	100.00	150.00								
214.76	1	2500.00	100.00	150.00								
235.99	1	1500.00	100.00	150.00								
235.99	1	2500.00	100.00	150.00								
240.00	6	2311.00	100.00	150.00								
257.22	1	1500.00	100.00	150.00								
257.22	1	2500.00	100.00	150.00								
270.00	6	1898.00	100.00	150.00								
278.45	1	1500.00	100.00	150.00								
278.45	1	2500.00	100.00	150.00								
290.00	5	1956.00	100.00	150.00								
299.68	1	1877.58	100.00	150.00								
299.68	1	2500.00	100.00	150.00								
300.00	6	2497.42	100.00	150.00								
320.00	5	2335.42	100.00	150.00								
330.00	6	2284.42	100.00	150.00								
360.00	6	2131.42	100.00	150.00								
390.00	6	1978.42	100.00	150.00								
400.00	7	1927.42	100.00	150.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 3 PIPELINE - AMMUNITION

TIME SEQUENCED SUPPLY LEVELS

USER NUMBER

TIME	ISP	1	2	3	4	5	6	7	8	9	10
0.00	2500.00	100.00	150.00								
30.00	2347.00	100.00	150.00								
60.00	2194.00	100.00	150.00								
90.00	2031.00	100.00	150.00								
120.00	1818.00	100.00	150.00								
150.00	1605.00	100.00	150.00								
180.00	2137.00	100.00	150.00								
210.00	1724.00	100.00	150.00								
240.00	2311.00	100.00	150.00								
270.00	1898.00	100.00	150.00								
300.00	2497.42	100.00	150.00								
330.00	2284.42	100.00	150.00								
360.00	2131.44	100.00	150.00								
390.00	1978.42	100.00	150.00								
400.00	1927.44	100.00	150.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 4 PIPELINE - AMMUNITION

SUPPLY RATE VARIATIONS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	2	3	4	5	6	7	8	9	10
0.00	0	5.10	2.00	3.00								
65.00	5	7.10	4.00	3.00								
160.00	5	10.10	4.00	6.00								
175.00	5	49.10	4.00	45.00								
180.00	5	47.10	2.00	45.00								
290.00	5	8.10	2.00	6.00								
320.00	5	5.10	2.00	3.00								
400.00	7	5.10	2.00	3.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 1 PIPELINE - OTHER SUPPLIES

EVENT CHRONOLOGY

TIME	EVENT TYPE NUMBER	EVENT DESCRIPTION
10.42	1	CARGO CARRIER ARRIVAL AT ISP
20.83	1	CARGO CARRIER ARRIVAL AT ISP
31.25	1	CARGO CARRIER ARRIVAL AT ISP
41.67	1	CARGO CARRIER ARRIVAL AT ISP
52.08	1	CARGO CARRIER ARRIVAL AT ISP
62.50	1	CARGO CARRIER ARRIVAL AT ISP
72.92	1	CARGO CARRIER ARRIVAL AT ISP
83.33	1	CARGO CARRIER ARRIVAL AT ISP
85.00	5	CONTINGENCY EVENT -- USER NUMBER 1
92.92	2	ISP DIPPING INTO EMERGENCY SUPPLIES
94.07	1	CARGO CARRIER ARRIVAL AT ISP
103.50	1	CARGO CARRIER ARRIVAL AT ISP
112.93	1	CARGO CARRIER ARRIVAL AT ISP
122.37	1	CARGO CARRIER ARRIVAL AT ISP
131.80	1	CARGO CARRIER ARRIVAL AT ISP
141.24	1	CARGO CARRIER ARRIVAL AT ISP
150.67	1	CARGO CARRIER ARRIVAL AT ISP
150.00	5	CONTINGENCY EVENT -- USER NUMBER 2
160.09	2	ISP DIPPING INTO EMERGENCY SUPPLIES
160.10	1	CARGO CARRIER ARRIVAL AT ISP
168.72	2	ISP DIPPING INTO EMERGENCY SUPPLIES
169.07	1	CARGO CARRIER ARRIVAL AT ISP
175.00	5	CONTINGENCY EVENT -- USER NUMBER 2
177.00	2	ISP DIPPING INTO EMERGENCY SUPPLIES
177.69	1	CARGO CARRIER ARRIVAL AT ISP
180.00	5	CONTINGENCY EVENT -- USER NUMBER 1
183.64	2	ISP DIPPING INTO EMERGENCY SUPPLIES
184.10	1	CARGO CARRIER ARRIVAL AT ISP
190.95	1	CARGO CARRIER ARRIVAL AT ISP
197.80	2	ISP DIPPING INTO EMERGENCY SUPPLIES
197.80	1	CARGO CARRIER ARRIVAL AT ISP
204.64	1	CARGO CARRIER ARRIVAL AT ISP
211.49	1	CARGO CARRIER ARRIVAL AT ISP
218.34	1	CARGO CARRIER ARRIVAL AT ISP
225.19	1	CARGO CARRIER ARRIVAL AT ISP
232.04	1	CARGO CARRIER ARRIVAL AT ISP
238.89	1	CARGO CARRIER ARRIVAL AT ISP
245.74	1	CARGO CARRIER ARRIVAL AT ISP
252.59	1	CARGO CARRIER ARRIVAL AT ISP
259.44	1	CARGO CARRIER ARRIVAL AT ISP
266.29	1	CARGO CARRIER ARRIVAL AT ISP
273.14	1	CARGO CARRIER ARRIVAL AT ISP
279.99	1	CARGO CARRIER ARRIVAL AT ISP
286.84	1	CARGO CARRIER ARRIVAL AT ISP
290.00	5	CONTINGENCY EVENT -- USER NUMBER 2
293.69	1	CARGO CARRIER ARRIVAL AT ISP
303.12	1	CARGO CARRIER ARRIVAL AT ISP
312.55	1	CARGO CARRIER ARRIVAL AT ISP

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

320,00	5	CONTINGENCY EVENT -- USER NUMBER 2
321,99	1	CARGO CARRIER ARRIVAL AT ISP
332,40	1	CARGO CARRIER ARRIVAL AT ISP
342,82	1	CARGO CARRIER ARRIVAL AT ISP
353,24	1	CARGO CARRIER ARRIVAL AT ISP
363,65	1	CARGO CARRIER ARRIVAL AT ISP
374,07	1	CARGO CARRIER ARRIVAL AT ISP
384,49	1	CARGO CARRIER ARRIVAL AT ISP
394,90	1	CARGO CARRIER ARRIVAL AT ISP
400,00	7	RUN TERMINATED BEFORE LAST CONTINGENCY HAS BEEN STABILIZED

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 2 PIPELINE - OTHER SUPPLIES

EVENT SEQUENCED SUPPLY LEVELS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	2	3	4	5	6	7	8	9	10
0.00	0	2000.00	1500.00	1200.00								
10.42	1	1500.00	1500.00	1200.00								
10.42	1	2000.00	1500.00	1200.00								
20.83	1	1500.00	1500.00	1200.00								
20.83	1	2000.00	1500.00	1200.00								
30.00	6	1560.00	1500.00	1200.00								
31.25	1	1500.00	1500.00	1200.00								
31.25	1	2000.00	1500.00	1200.00								
41.67	1	1500.00	1500.00	1200.00								
41.67	1	2000.00	1500.00	1200.00								
52.08	1	1500.00	1500.00	1200.00								
52.08	1	2000.00	1500.00	1200.00								
60.00	6	1620.00	1500.00	1200.00								
62.50	1	1500.00	1500.00	1200.00								
62.50	1	2000.00	1500.00	1200.00								
72.92	1	1500.00	1500.00	1200.00								
72.92	1	2000.00	1500.00	1200.00								
83.33	1	1500.00	1500.00	1200.00								
83.33	1	2000.00	1500.00	1200.00								
85.00	5	1920.00	1500.00	1200.00								
90.00	6	1655.00	1500.00	1200.00								
92.92	2	1500.00	1500.00	1200.00								
94.07	1	1439.53	1500.00	1200.00								
94.07	1	2000.00	1500.00	1200.00								
103.50	1	1500.00	1500.00	1200.00								
103.50	1	2000.00	1500.00	1200.00								
112.93	1	1500.00	1500.00	1200.00								
112.93	1	2000.00	1500.00	1200.00								
120.00	6	1625.47	1500.00	1200.00								
122.37	1	1500.00	1500.00	1200.00								
122.37	1	2000.00	1500.00	1200.00								
131.80	1	1500.00	1500.00	1200.00								
131.80	1	2000.00	1500.00	1200.00								
141.24	1	1500.00	1500.00	1200.00								
141.24	1	2000.00	1500.00	1200.00								
150.00	6	1535.47	1500.00	1200.00								
150.67	1	1500.00	1500.00	1200.00								
150.67	1	2000.00	1500.00	1200.00								
160.00	5	1505.47	1500.00	1200.00								
160.09	2	1500.00	1500.00	1200.00								
160.10	1	1499.48	1500.00	1200.00								
160.10	1	1999.48	1500.00	1200.00								
168.72	2	1500.00	1500.00	1200.00								
169.07	1	1479.67	1500.00	1200.00								
169.07	1	2000.00	1500.00	1200.00								
175.00	5	1655.80	1500.00	1200.00								
177.60	2	1500.00	1500.00	1200.00								
177.09	1	1415.28	1500.00	1200.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

177.69	1	1946.28	1500.00	1200.00
180.00	5	1765.80	1500.00	1200.00
180.00	6	1765.80	1500.00	1200.00
183.64	2	1500.00	1500.00	1200.00
184.10	1	1466.76	1500.00	1200.00
184.10	1	2000.00	1500.00	1200.00
190.95	1	1500.00	1500.00	1200.00
190.95	1	2000.00	1500.00	1200.00
197.80	2	1500.00	1500.00	1200.00
197.80	1	1500.00	1500.00	1200.00
197.80	1	2000.00	1500.00	1200.00
204.64	1	1500.00	1500.00	1200.00
204.64	1	2000.00	1500.00	1200.00
210.00	6	1609.04	1500.00	1200.00
211.49	1	1500.00	1500.00	1200.00
211.49	1	2000.00	1500.00	1200.00
218.34	1	1500.00	1500.00	1200.00
218.34	1	2000.00	1500.00	1200.00
225.19	1	1500.00	1500.00	1200.00
225.19	1	2000.00	1500.00	1200.00
232.04	1	1500.00	1500.00	1200.00
232.04	1	2000.00	1500.00	1200.00
238.89	1	1500.00	1500.00	1200.00
238.89	1	2000.00	1500.00	1200.00
240.00	6	1919.04	1500.00	1200.00
245.74	1	1500.00	1500.00	1200.00
245.74	1	2000.00	1500.00	1200.00
252.59	1	1500.00	1500.00	1200.00
252.59	1	2000.00	1500.00	1200.00
259.44	1	1500.00	1500.00	1200.00
259.44	1	2000.00	1500.00	1200.00
266.29	1	1500.00	1500.00	1200.00
266.29	1	2000.00	1500.00	1200.00
270.00	6	1729.04	1500.00	1200.00
273.14	1	1500.00	1500.00	1200.00
273.14	1	2000.00	1500.00	1200.00
279.99	1	1500.00	1500.00	1200.00
279.99	1	2000.00	1500.00	1200.00
286.84	1	1500.00	1500.00	1200.00
286.84	1	2000.00	1500.00	1200.00
290.00	5	1769.04	1500.00	1200.00
293.69	1	1573.71	1500.00	1200.00
293.69	1	2000.00	1500.00	1200.00
300.00	6	1665.33	1500.00	1200.00
303.12	1	1500.00	1500.00	1200.00
303.12	1	2000.00	1500.00	1200.00
312.55	1	1500.00	1500.00	1200.00
312.55	1	2000.00	1500.00	1200.00
320.00	5	1605.33	1500.00	1200.00
321.99	1	1509.94	1500.00	1200.00
321.99	1	2000.00	1500.00	1200.00
330.00	6	1615.39	1500.00	1200.00
332.40	1	1500.00	1500.00	1200.00
332.40	1	2000.00	1500.00	1200.00
342.82	1	1500.00	1500.00	1200.00
342.82	1	2000.00	1500.00	1200.00
353.24	1	1500.00	1500.00	1200.00
353.24	1	2000.00	1500.00	1200.00
360.00	6	1675.39	1500.00	1200.00
363.65	1	1500.00	1500.00	1200.00
363.65	1	2000.00	1500.00	1200.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

374.07	1	1500.00	1500.00	1200.00
374.07	1	2200.00	1500.00	1200.00
384.49	1	1500.00	1500.00	1200.00
384.49	1	2000.00	1500.00	1200.00
390.00	6	1735.39	1500.00	1200.00
394.90	1	1500.00	1500.00	1200.00
394.90	1	2000.00	1500.00	1200.00
400.00	7	1755.39	1500.00	1200.00

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 3 PIPELINE - OTHER SUPPLIES

TIME SEQUENCED SUPPLY LEVELS

		USER NUMBER									
TIME	ISP	1	2	3	4	5	6	7	8	9	10
0.00	2000.00	1500.00	1200.00								
30.00	1560.00	1500.00	1200.00								
60.00	1620.00	1500.00	1200.00								
90.00	1655.00	1500.00	1200.00								
120.00	1625.47	1500.00	1200.00								
150.00	1535.47	1500.00	1200.00								
180.00	1765.80	1500.00	1200.00								
210.00	1609.04	1500.00	1200.00								
240.00	1919.04	1500.00	1200.00								
270.00	1729.04	1500.00	1200.00								
300.00	1665.33	1500.00	1200.00								
330.00	1615.39	1500.00	1200.00								
360.00	1675.39	1500.00	1200.00								
390.00	1735.39	1500.00	1200.00								
400.00	1755.39	1500.00	1200.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Continued)

TABLE 4 PIPELINE - OTHER SUPPLIES

SUPPLY RATE VARIATIONS

TIME	EVENT TYPE NUMBER	ISP	USER NUMBER 1	2	3	4	5	6	7	8	9	10
0.00	0	48.00	25.00	20.00								
85.00	5	53.00	30.00	20.00								
160.00	5	58.00	30.00	25.00								
175.00	5	78.00	30.00	45.00								
180.00	5	73.00	25.00	45.00								
290.00	5	53.00	25.00	25.00								
320.00	5	48.00	25.00	20.00								
400.00	7	48.00	25.00	20.00								

Figure IV-20 SAMPLE PROBLEM OUTPUT TABLES (Concluded)

REFERENCES

1. E. H. Means and L. L. Anderson, "BALFRAM Computer Operation Manual for the Staff of the Commander in Chief Pacific," SRI/NWRC-TN-9, September 1974 (DDC AD A-002491).

2. E. H. Means, C. L. Phillips, and S. E. Young, "BALFRAM User Manual for the Staff of the Commander in Chief Pacific," SRI/NWRC-TN-52, September 1974 (DDC AD A-004297).

3. O. F. Forsyth, C. L. Phillips, and S. E. Young, "BALFRAM Program Maintenance Manual for the Staff of the Commander in Chief Pacific," SRI/NWRC-TN-53, December 1974 (DDC AD A-009845).

4. E. H. Means, "BALFRAM Seminar Guide," Volumes I and II, SRI/NWRC-TN-63, February 1976.

APPENDIX

SUPPLY DISTRIBUTION MODULE COMPUTER PROGRAM

A. Input Formats

All inputs to the SUPPLY DISTRIBUTION MODULE Computer Program are read from a series of input data cards, or equivalently, from an input data file containing 80 character data records (each input record corresponding to an input data card). Table A-1 presents a summary description of each input data card including the card formats, input variables, variable descriptions, and variable measurement units. Some of the card numbers apply to a set of input cards. For example, Cards 6.P.I refer to a set of NB data cards for Pipline P's set of data cards, where NB is the number of users.

Table A-1

INPUT DATA CARDS

Card Number and Format	Input Variable	Description	Measurement Units
Card 1 (2I6)	ITP	Integer-valued printout interval	days
	ITDUR	Integer-valued scheduled run duration	days
Card 2 (I')	NB	Number of users	
One set of Cards 3 - 6 for each Pipeline P (P=1,2,3)			
Card 3.P (A30)	PN(P)	Pipeline name for Pipeline P	
Card 4.P (F9.1, F5.1, 2F9.1, F5.1)	SCC(P)	Cargo carrier capacity for Pipeline P	ST or kbbl
	SCS(P)	Cargo carrier speed for Pipeline P	knots
	SCL(P)	Cargo carrier loading rate for Pipeline P	ST/day or kbbl/day
	SPR(P)	Cargo preparation rate for Pipeline P	ST/day or kbbl/day
	SDT(P)	Cargo carrier recycle downtime for Pipeline P	days
Card 5.P (2F9.1, F7.2, 2F9.1, F9.2, F5.1)	MSC(P)	ISP storage capacity for Pipeline P	ST or kbbl
	MSU(P)	Cargo carrier unloading rate at ISP for Pipeline P	ST/day or kbbl/day
	MDR(P)	ISP own supply demand rate for Pipeline P	ST/day or kbbl/day
	MES(P)	ISP emergency stores level for Pipeline P	ST or kbbl
	MCS(P)	ISP critical stores level for Pipeline P	ST or kbbl
	MSD(P)	Transit distance between supply source and ISP for Pipeline P	nmi
	MOT(P)	ISP order time for Pipeline P	days

Table A-1 (Concluded)

Loop	Card Number and Format	Input Variable	Description	Measurement Units
I = 1, NB	Card 6.P.I (F7.2, F5.3, 3F9.1)	BIR(I,P)	Initial demand rate for User I for Pipeline P	ST/day or kbbl/day
		BIP(I,P)	Initial essentiality priority number for User I for Pipeline P	
		BML(I,P)	Maximum supply level for User I for Pipeline P	ST or kbbl
		BSL(I,P)	Safety supply level for User I for Pipeline P	ST or kbbl
		BCL(I,P)	Critical supply level for User I for Pipeline P	ST or kbbl
	Card 7 (I2)	NOC	Number of contingency events	
NCO = 1, NOC	Card 8.NCO (I2, F7.1, 3F7.2, 3F5.3)	CUN(NCO)	User number associated with Contingency Event NCO	
		TC(NCO)	Time of occurrence of Contingency Event NCO	days
		CUD(NCO,1)	User demand rate for Pipeline 1 after occurrence of Contingency Event NCO	ST/day or kbbl/day
		CUD(NCO,2)	User demand rate for Pipeline 2 after occurrence of Contingency Event NCO	ST/day or kbbl/day
		CUD(NCO,3)	User demand rate for Pipeline 3 after occurrence of Contingency Event NCO	ST/day or kbbl/day
		CUP(NCO,1)	User essentiality priority number for Pipeline 1 after occurrence of Contingency Event NCO	
		CUP(NCO,2)	User essentiality priority number for Pipeline 2 after occurrence of Contingency Event NCO	
		CUP(NCO,3)	User essentiality priority number for Pipeline 3 after occurrence of Contingency Event NCO	

B. Program Nomenclature

1. Program PIPLIN

BCL(I,P)	Critical supply level for User I for Pipeline P.
BIG(I)	Indicator denoting whether or not User I is active (BIG(I)=0,No; BIG(I)=1,Yes).
BIP(I,P)	Present normal essential priority for User I for Pipeline P.
BIR(I,P)	Initial demand rate for User I for Pipeline P.
BL(I,P)	Present supply level for User I for Pipeline P.
BML(I,P)	Maximum supply level for User I for Pipeline P.
BP(I,P)	Present essential priority for User I for Pipeline P.
BPOLD	Previous essential priority for user and pipeline being processed.
BR(I,P)	Present demand rate for User I for Pipeline P.
BS(I,P)	Present supply rate for User I for Pipeline P.
BSL(I,P)	Safety supply level for User I for Pipeline P.
BSOLD	Previous supply rate for user and pipeline being processed.
CAR	Amount of expected shortfall to be made up at time of contingency event being processed.
CL(P)	Cargo carrier load for Pipeline P.
CLI	Cargo carrier load for next scheduled cargo carrier for pipeline being processed.
CLOLD	Previous value of cargo carrier load for pipeline being processed.
CLP	Cargo carrier load for next scheduled non-enroute cargo carrier for pipeline being processed.
CT	Current time.
CUD(NCO,P)	User demand rate for Pipeline P after occurrence of contingency event NCO.
CUN(NCO)	User number associated with contingency event NCO.

Program PIPLIN, continued

CUP(NCO,P)	User essentiality priority number for Pipeline P after occurrence of contingency event NCO.
DC(J,P)	Cargo carrier load for cargo carrier J in Pipeline P.
DELT	Difference in time of arrival between next scheduled non-enroute cargo carrier and last scheduled enroute cargo carrier for pipeline being processed.
DT(J,P)	Cargo carrier arrival time for cargo carrier J in Pipeline P.
ESP(P)	Indicator denoting whether or not ISP is drawing from emergency supplies for Pipeline P.
ET	Event type number for event currently being processed.
I	Index number for user (also used as a dummy index).
IC	Contingency pipeline counter.
IJ	Indicator denoting whether or not there is another contingency event involving an active user (IJ=0,No; IJ=1,Yes).
IP	Dummy index number for pipelines.
IP1	File number of Event Chronology Table for pipeline being processed.
IP2	File number of Event Sequenced Supply Level Table for pipeline being processed.
IP3	File number of Time Sequenced Supply Level Table for pipeline being processed.
IP4	File number of Supply Rate Variation Table for pipeline being processed.
IT1	Number of new interim cargo carriers to be scheduled immediately for pipeline and contingency event being processed.
ITDUR	Integer-valued scheduled run duration.

ITEM	Number of new interim cargo carriers to be scheduled for pipeline and contingency event being processed.
ITERM(P)	Indicator denoting whether or not Pipeline P has stabilized (ITERM(P)=0,No; ITERM(P)=1,Yes).
ITP	Integer-valued printout interval.
IW	Indicator denoting whether or not event being processed is a User Withdrawal Event (IW=0,No; IW=1,Yes).
J	Index number for scheduled cargo carrier (also used as a dummy index).
JE	User number or special event number (NB1, NB2, or NB3).
JJ	Dummy index used to denote contingency event number.
JP	Pipeline number generating event to be processed.
JT	User number generating contingency event that is to be processed.
K	Dummy index used to denote contingency event number.
KP	Dummy index number for pipelines.
MCS(P)	ISP critical stores level for Pipeline P.
MD(P)	Present total demand rate on the ISP for Pipeline P.
MDOLD	Previous total demand rate on ISP for pipeline being processed.
MDP(P)	Present total user demand rate on the ISP for Pipeline P.
MDR(P)	ISP own supply demand rate for Pipeline P.
MES(P)	ISP emergency stores level for Pipeline P.
MK(K)	Dummy array used to transfer output from internal files to program output file.
MOT(P)	ISP order time for Pipeline P.

MSC(P)	ISP storage capacity for Pipeline P.
MSD(P)	Transit distance between supply source and ISP for Pipeline P.
MSU(P)	Cargo carrier unloading rate at ISP for Pipeline P.
N	Dummy index used to denote contingency event number.
NB	Number of users.
NB1	Special event number for ISP related event (NB1=NB+1).
NB2	Special event number for contingency event (NB2=NB+2).
NB3	Special event number for scheduled run control operation (NB3=NB+3).
NC(P)	Number of cargo carriers required to maintain static pipeline operation for Pipeline P.
NC1	Number of cargo carriers scheduled for static pipeline operation for pipeline being processed.
NCO	Index number for contingency event.
NCO1	Dummy index used to denote contingency event number.
NIC(P)	Number of interim cargo carriers in Pipeline P.
NIC1	Index number denoting first scheduled cargo carrier for static pipeline operation for pipeline being processed.
NOC	Number of contingency events.
NOC1	Index number denoting one more than the number of contingency events.
NTC(P)	Total number of scheduled cargo carriers in Pipeline P.
P	Index number for pipelines.
PN(P)	Pipeline name for Pipeline P.

REM	Dummy variable used to denote the difference between the real value and the integer value of a variable.
SCC(P)	Cargo carrier capacity for Pipeline P.
SCL(P)	Cargo carrier loading rate for Pipeline P.
SCS(P)	Cargo carrier speed for Pipeline P.
SDT(P)	Cargo carrier recycle downtime for Pipeline P.
SE(I,P)	Next event type for User I (I=1,...,NB) or Special Event I (I=NB1, NB2, or NB3) for pipeline P.
SFM	Total amount of supply surplus that can be distributed for pipeline being processed.
SFM1	Amount of supply surplus that can be distributed immediately for pipeline being processed.
SFM2	Additional amount of supply surplus that can be distributed before arrival of next scheduled cargo carrier for pipeline being processed.
SL(P)	Present ISP supply level for Pipeline P.
SLT	ISP supply level, including any surplus, that may be available for pipeline being processed.
SOF	Projected supply overfall for pipeline being processed.
SPR(P)	Cargo preparation rate for Pipeline P.
SR(P)	Present ISP supply rate for Pipeline P.
SROLD	Previous ISP supply rate for pipeline being processed.
SRP(P)	Present user supply rate for Pipeline P.
SRT	Maximum allowable ISP supply rate for pipeline being processed.
T	Dummy variable used in determining time of next event to be processed.
TC(NCO)	Time of occurrence of Contingency Event NCO.
TCM	Maxumum allowable time-between-arrivals for cargo carriers at ISP for pipeline being processed.

TCP	Cargo carrier's cycle time for pipeline being processed.
TCY(P)	Cargo carrier's maximum cycle time for Pipeline P.
TDUR	Real-valued scheduled run duration.
TE(I,P)	Next event time for User I (I=1,...,NB) or Special Event I (I=NB1, NB2, or NB3) for Pipeline P.
TEM	Dummy variable used for several diverse computations.
TEM1	Dummy variable used to determine time of occurrence of next contingency event involving an active user.
TFA	Time of arrival of first possible newly scheduled cargo carrier for pipeline being processed.
TL	Time of arrival of last enroute cargo carrier for pipeline being processed.
TLA	Time of arrival of last interim cargo carrier for pipeline being processed.
TLAR(P)	Time of arrival of previous arriving cargo carrier for Pipeline P.
TLE(P)	Time of last processed event for Pipeline P.
TN	Time of arrival of next departing cargo carrier for pipeline being processed.
TP	Real-valued printout interval.
TPA	Possible time of arrival of next non-enroute cargo carrier for pipeline being processed.
TR(P)	Number of supply days provided by a cargo carrier to an ISP in Pipeline P.
TSA	Time of arrival of next scheduled non-enroute cargo carrier for pipeline being processed.
WB(I)	Supply allocation weighting factor for User I for pipeline being processed.

2. <u>Subroutine REVISE</u>

CL(P)	Cargo carrier load for Pipeline P.
MD(P)	Demand rate on ISP for Pipeline P.
MES(P)	Emergency supply level for ISP for Pipeline P.
MSC(P)	Storage capacity for ISP for Pipeline P.
MSU(P)	Cargo unloading rate for ISP for Pipeline P.
NC(P)	Number of cargo carriers required to maintain Pipeline P.
P	Index number for pipeline being processed.
REM	Dummy variable used in determining NC(P).
SCC(P)	Cargo carrier capacity for Pipeline P.
SCL(P)	Cargo loading rate at supply source for Pipeline P.
SPR(P)	Cargo preparation rate at supply source for Pipeline P.
TCM	Maximum allowable time-between-arrivals for cargo carriers at ISP for pipeline being processed.
TCP	Cargo carrier's cycle time for pipeline being processed.
TCY(P)	Cargo carrier's maximum cycle time for Pipeline P.
TEM	Dummy variable used in determining TR(P) and NC(P).
TR(P)	Number of supply days provided by a cargo carrier to an ISP in Pipeline P.

3. <u>Subroutine NEXTEV</u>

BCL(I,P)	Critical supply level for User I for Pipeline P.
BIG(I)	Indicator denoting whether or not User I is active (BIG(I)=0,No; BIG(I)=1,Yes).
BL(I,P)	Present supply level for User I for Pipeline P.
BR(I,P)	Present demand rate for User I for Pipeline P.
BS(I,P)	Present supply rate for User I for Pipeline P.
BSL(I,P)	Safety supply level for User I for Pipeline P.
CT	Current time.
I	Index number for user.

NB	Number of users.
P	Index number for pipeline being processed.
SE(I,P)	Next event type number for User I for Pipeline P.
TE(I,P)	Time of occurrence of next event for User I for Pipeline P.

4. Subroutine ALLOC

B(I)	Ratio of present essential priority to present demand rate for User I.
BIG(I)	Indicator denoting whether or not User I is active (BIG(I)=0,No; BIG(I)=1,Yes).
BP(I,P)	Present essential priority for User I for Pipeline P.
BR(I,P)	Present demand rate for User I for Pipeline P.
I	Index number for user.
NB	Number of users.
P	Index number for pipeline being processed.
PRO	Product of all B(I)'s.
SUM	Sum of weighting factors (unnormalized).
WB(I)	Supply allocation weighting factor for User I for pipeline being processed.

5. Subroutine SHTFAL

BIG(I)	Indicator denoting whether or not User I is active (BIG(I)=0,No; BIG(I)=1,Yes).
BIP(I,P)	Present normal essential priority for User I for Pipeline P.
BL(I,P)	Present supply level for User I for Pipeline P.
BML(I,P)	Maximum supply level for User I for Pipeline P.
BP(I,P)	Present essential priority for User I for Pipeline P.
BSL(I,P)	Safety supply level for User I for Pipeline P.
I	Index number for user.

Subroutine SHTFAL, continued

NB	Number of users.
P	Index number for pipeline being processed.
SE(I,P)	Next event type number for User I for Pipeline P.
SF(I)	Dummy variable used to denote shortfall for User I for pipeline being processed.
SFM	Supply surplus for pipeline being processed.
SL(P)	ISP supply level for pipeline P.
SSF	Shortfall existing for users for Pipeline P.

C. Program Listing

```
      PROGRAM PIPLIN
      COMMON /BLOCK1/ TCM,MSC(3),MES(3),MD(3),SCC(3),TR(3),
     1                CL(3),TCY(3),TCP,SPR(3),SCL(3),
     2                MSU(3),NC(3)
      REAL   MD,MSC,MSU,MES
      COMMON /BLOCK2/ NB,BIG(10),SE(13,3),TE(13,3),BL(10,3),BSL(10,3),
     1    BML(10,3),BCL(10,3),BR(10,3),BIR(10,3),BS(10,3),BP(10,3),
     2    BIP(10,3),MB(10),SL(3),SFM,CT
      INTEGER    SE,BIG
      DIMENSION  DC(100,3),DT(100,3),TC(99),CUD(99,3),CUP(99,3),
     1           SCS(3),SDT(3),SR(3),SRP(3),NIC(3),NTC(3),TLE(3),
     2           ITERM(3),TLAR(3)
      REAL    MDR(3),MDP(3),MCS(3),MSD(3),MOT(3),MDOLD
      INTEGER   CUN(99),ESP(3),ET,P
      CHARACTER*1 MK(132)
      CHARACTER*30 PN(3)
 1000 FORMAT(2I6)
 1001 FORMAT(F9.1,F5.1,F9.1,F9.1,F5.1)
 1002 FORMAT(F9.1,F9.1,F7.2,F9.1,F9.1,F9.2,F5.1)
 1003 FORMAT(F7.2,F5.3,F9.1,F9.1,F9.1)
 1004 FORMAT(I2,F7.1,3F7.2,3F5.3)
 1005 FORMAT(132A1)
 1006 FORMAT(I2)
 1007 FORMAT(A30)
 2000 FORMAT(T5,F9.2,T22,11(F8.2,1X))
 2001 FORMAT(T2,F9.2,T16,I1,T22,11(F8.2,1X))
 2011 FORMAT(T5,F9.2,T20,1H1,T31,28HCARGO CARRIER ARRIVAL AT ISP)
 2012 FORMAT(T5,F9.2,T20,1H2,T31,28HISP DIPPING INTO EMERGENCY S,
     1 7HUPPLIES)
 2013 FORMAT(T5,F9.2,T20,1H3,T31,53HSUPPLY LEVEL DROPS BELOW SAFETY LEVE
     1L -- USER NUMBER ,I2)
 2014 FORMAT(T5,F9.2,T20,1H4,T31,50HSUPPLY LEVEL REACHES CRITICAL LEVEL
     1-- USER NUMBER ,I2/T35,41HUSER WITHDRAWS -- INSTIGATING PIPELINE -
     2 ,A30)
 2015 FORMAT(T5,F9.2,T20,1H5,T31,26HCONTINGENCY EVENT -- USER ,
     1 7HNUMBER ,I2)
 2016 FORMAT(T5,F9.2,T20,1H6,T31,23HROUTINE PRINT-OUT EVENT)
 2017 FORMAT(T5,F9.2,T20,1H7,T31,27HRUN TERMINATED BEFORE LAST ,
     1 31HCONTINGENCY HAS BEEN STABILIZED)
 2018 FORMAT(T5,F9.2,T20,1H7,T31,26HRUN TERMINATED--ALL USERS ,
     1 14HHAVE WITHDRAWN)
 2019 FORMAT(T5,F9.2,T20,1H7,T31,27HRUN TERMINATED--ISP CANNOT ,
     1 20HMAINTAIN SELF-SUPPLY,3X,11HPIPELINE - ,A30)
 2020 FORMAT(T5,F9.2,T20,1H7,T31,21HRUN TERMINATED--LAST ,
     1 31HCONTINGENCY HAS BEEN STABILIZED)
 2021 FORMAT(T5,F9.2,T20,1H7,T31,31HRUN TERMINATED--SL(P).NE.MES(P),
     1        3X,11HPIPELINE - ,A30)
 2022 FORMAT(T5,F9.2,T20,1H7,T31,27HRUN TERMINATED--BL(I,P).NE.,
     1 11HBSL(I,P),I=,I2,3X,11HPIPELINE - ,A30)
 2023 FORMAT(T5,F9.2,T20,1H7,T31,27HRUN TERMINATED--BL(I,P).NE.,
     1 11HBCL(I,P),I=,I2,3X,11HPIPELINE - ,A30)
 2024 FORMAT(T5,F9.2,T20,1H7,T31,25HUSER WITHDRAWS AND THERE ,
     1 31HARE NO INTERIM CARRIERS ENROUTE,3X,11HPIPELINE - ,A30)
 2025 FORMAT(T31,32HRUN TERMINATED--INPUT READ ERROR)
 3001 FORMAT(1H1/////T45,7HTABLE 1,3X,11HPIPELINE - ,A30//T53,16HEVENT C
     1HRONOLOGY/T18,5HEVENT/T19,4HTYPE/T8,4HTIME,T18,6HNUMBER,T50,
     2 17HEVENT DESCRIPTION//)
 3002 FORMAT(1H1/////T45,7HTABLE 2,3X,11HPIPELINE - ,A30//T47,16HEVENT S
     1EQUENCED ,13HSUPPLY LEVELS/T14,5HEVENT/T15,4HTYPE,T56,
     2 11HUSER NUMBER/T5,4HTIME,T14,6HNUMBER,T25,3HISP,T35,1H1,
     3 T44,1H2,T53,1H3,T62,1H4,T71,1H5,T80,1H6,T89,1H7,T98,1H8,
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     4 T107,1H9,T115,2H10//)
3003 FORMAT(1H1/////T45,7HTABLE 3,3X,11HPIPELINE - ,A30//T48,15HTIME SE
     1QUENCED ,13HSUPPLY LEVELS//T56,11HUSER NUMBER/T8,4HTIME,T25,3HISP,
     2 T35,1H1,T44,1H2,T53,1H3,T62,1H4,T71,1H5,T80,1H6,T89,1H7,
     3 T98,1H8,T107,1H9,T115,2H10//)
3004 FORMAT(1H1/////T45,7HTABLE 4,3X,11HPIPELINE - ,A30//T50,11HSUPPLY
     1RATE,11H VARIATIONS/T14,5HEVENT/T15,4HTYPE,T56,
     2 11HUSER NUMBER/T5,4HTIME,T14,6HNUMBER,T25,3HISP,T35,1H1,
     3 T44,1H2,T53,1H3,T62,1H4,T71,1H5,T80,1H6,T89,1H7,T98,1H8,
     4 T107,1H9,T115,2H10//)
      OPEN(UNIT=5,FILE='PIPLIN.DAT',READONLY,STATUS='OLD')
      OPEN(UNIT=7,FILE='PIPLIN.LIS',STATUS='NEW')
      OPEN(UNIT=8,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=9,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=10,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=11,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=12,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=13,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=14,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=15,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=16,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=17,STATUS='NEW',DISP='DELETE')
      OPEN(UNIT=18,STATUS='NEW',DISP='DELETE')
      READ(5,1000,ERR=900,END=900)  ITP,ITDUR
      TP=1.*ITP
      TDUR=1.*ITDUR
      READ(5,1006)NB
      DO 3 P=1,3
      READ(5,1007)PN(P)
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      WRITE(IP1,3001)PN(P)
      WRITE(IP2,3002)PN(P)
      WRITE(IP3,3003)PN(P)
      WRITE(IP4,3004)PN(P)
      READ(5,1001,ERR=900,END=900) SCC(P),SCS(P),SCL(P),SPR(P)
     1    ,SDT(P)
      READ(5,1002,ERR=900,END=900) MSC(P),MSU(P),MDR(P),MES(P),
     1      MCS(P),MSD(P),MOT(P)
      DO 1 I=1,NB
       READ(5,1003,ERR=900,END=900)BIR(I,P),BIP(I,P),BML(I,P),BSL(I,P),
     1 BCL(I,P)
    1 CONTINUE
    3 CONTINUE
      READ(5,1006)NOC
      DO 2 I=1,NOC
      READ(5,1004,END=900,ERR=900)CUN(I),TC(I),(CUD(I,P),P=1,3),
     1 (CUP(I,P),P=1,3)
    2 CONTINUE
      NOC1=NOC+1
      TC(NOC1)=1E9
C
C     ESTABLISH STATIC PIPELINE FLOW PARAMETERS AND CARRIER DELIVERY
C     TIMES.
C
      DO 16 P=1,3
      MD(P)=MDR(P)
      DO 10 I=1,NB
   10 MD(P)=MD(P)+BIR(I,P)
```

```
      MDP(P)=MD(P)-MDM(P)
      TCY(P)=(1./SPH(P)+1./SCL(P)+1./MSU(P))*SCC(P) +
     1     2*MSD(P)/(24.*SCS(P)) + SDT(P)
      CALL REVISE(P)
      SR(P)=MD(P)
      SRP(P)=MDP(P)
      SL(P)=MSC(P)
      ESP(P)=0
      NTC(P)=NC(P)+1
      NIC(P)=0
      DO 15 J=1,NTC(P)
      DT(J,P)=J*TK(P)
   15 DC(J,P)=CL(P)
   16 CONTINUE
C
C     INITIALIZE RUNNING PARAMETERS
C
      IC=0
      JP=1
      NB1=NB+1
      NB2=NB+2
      NB3=NB+3
      NCO=1
      IW=0
      DO 25 P=1,3
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      TLE(P)=0.
      DO 20 I=1,NB
      BR(I,P)=BIR(I,P)
      BP(I,P)=BIP(I,P)
      BL(I,P)=BML(I,P)
      BS(I,P)=BIR(I,P)
      TE(I,P)=1E9
      SE(I,P)=0
   20 BIG(I)=1
      CT=0.
      ET=0
      TE(NB1,P)=DT(1,P)
      SE(NB1,P)=1
      TE(NB2,P)=TC(1)
      SE(NB2,P)=5
      TE(NB3,P)=TP
      SE(NB3,P)=6
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP3,2000)CT,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
   25 CONTINUE
   50 TLE(JP)=CT
C
C      DETERMINE NEXT EVENT TIME, PARTICIPANT, AND TYPE TO BE
C      PROCESSED.
C
   51 T=1E10
      JE=0
      DO 55 P=1,3
      DO 55 I=1,NB3
      IF(T.LE.TE(I,P)) GO TO 55
      T=TE(I,P)
```

```
      JE=I
      JP=P
   55 CONTINUE
      IF(JE.EQ.0)GO TO 9000
      IF(SE(JE,JP).NE.5)GO TO 59
      JT=CUN(NCO)
      IF(BIG(JT).EQ.1)GO TO 59
      NCO=NCO+1
      DO 57 P=1,3
      TE(NB2,P)=TC(NCO)
   57 CONTINUE
      GO TO 51
   59 CT=T
      ET=SE(JE,JP)
      P=JP
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
C
C     COMPUTE PRESENT SUPPLY LEVELS
C
      DO 60 I=1,NB
      BL(I,P)=BL(I,P)-(BR(I,P)-BS(I,P))*(CT-TLE(P))
   60 CONTINUE
      SL(P)=SL(P)-SR(P)*(CT-TLE(P))
      IF(ET.EQ.5)GO TO 500
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      GO TO (100,200,300,400,500,600,700)ET
C
C     PROCESS THE ARRIVAL OF A CARGO CARRIER
C
  100 SL(P)=SL(P)+DC(1,P)
      TLAR(P)=CT
      SROLD=SR(P)
      ITERM(P)=0
      WRITE(IP1,2011)CT
      IF(NIC(P).NE.0)GO TO 105
      ITERM(P)=1
      IF(NCO.GT.NOC)GO TO 104
  101 DO 102 I=2,NTC(P)
      DT(I-1,P)=DT(I,P)
      DC(I-1,P)=DC(I,P)
  102 CONTINUE
      DT(NTC(P),P)=DT(NTC(P)-1,P)+TR(P)
      DC(NTC(P),P)=DC(NTC(P)-1,P)
      ESP(P)=0
      TE(NB1,P)=DT(1,P)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      GO TO 50
  104 DO 103 IP=1,3
      IF(IP.EQ.P)GO TO 103
      IF(ITERM(IP).NE.1)GO TO 101
  103 CONTINUE
      ET=7
      DO 1050 P=1,3
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
```

```
      WRITE(IP3,2000)CT,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      WRITE(IP1,2020)CT
 1050 CONTINUE
      GO TO 9000
  105 CONTINUE
      DO 107 I=2,NTC(P)
      DT(I-1,P)=DT(I,P)
      DC(I-1,P)=DC(I,P)
  107 CONTINUE
      TE(NB1,P)=DT(1,P)
      NTC(P)=NTC(P)-1
      NIC(P)=NIC(P)-1
      IF(SL(P).LE.MES(P)+.01)GO TO 120
      SR(P)=MD(P)
      DO 110 I=1,NB
      BS(I,P)=BIG(I)*BR(I,P)
      TE(I,P)=1E9
  110 CONTINUE
      IF(SROLD.NE.SR(P))WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      IF(SL(P).GT.MSC(P))GO TO 115
      SFM1=0.
      GO TO 140
  115 SFM1=SL(P)-MSC(P)
      GO TO 140
  120 CONTINUE
      SFM1=0.
      SRT=(SL(P)-MCS(P))/(DT(1,P)-CT)
      IF(SRT.LT.MD(P))GO TO 128
      SR(P)=MD(P)
      DO 124 I=1,NB
      BS(I,P)=BIG(I)*BR(I,P)
      TE(I,P)=1E9
  124 CONTINUE
      IF(SROLD.NE.SR(P))WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      GO TO 140
  128 SR(P)=SRT
      SRP(P)=SR(P)-MDK(P)
      MDP(P)=MD(P)-MDK(P)
      IF(SRP(P).GE.0.)GO TO 132
      ET=7
      DO 130 P=1,3
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      WRITE(IP1,2019)CT,PN(JP)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP3,2000)CT,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
  130 CONTINUE
      GO TO 9000
  132 CALL ALLOC(P)
      DO 136 I=1,NB
      IF(BIG(I).EQ.0)GO TO 136
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  136 CONTINUE
      IF(SROLD.NE.SR(P))WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      CALL NEXTEV(P)
      GO TO 180
  140 SFM2=AMAX1(0.,SL(P)-SR(P)*(DT(1,P)-CT)-MCS(P))
```

```
      SFM=SFM1+SFM2
      IF(SFM.LE.0.)GO TO 180
      DO 145 I=1,NB
      IF(SE(I,P).NE.0)GO TO 150
  145 CONTINUE
      GO TO 180
  150 CALL SHTFAL(P)
  180 CONTINUE
      IF(SL(P).GT.MES(P)+.01)GO TO 185
      ESP(P)=1
      SE(NB1,P)=1
      TE(NB1,P)=DT(1,P)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      GO TO 50
  185 ESP(P)=0
      SLT=SL(P)
      SL(P)=AMIN1(SLT,MSC(P))
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      TEM=CT+(SL(P)-MES(P))/SR(P)
      IF(TEM.LT.DT(1,P))GO TO 190
      SE(NB1,P)=1
      TE(NB1,P)=DT(1,P)
      GO TO 50
  190 SE(NB1,P)=2
      TE(NB1,P)=TEM
      GO TO 50
C
C     PROCESS THE ISP DIPPING INTO EMERGENCY SUPPLIES
C
  200 WRITE(IP1,2012)CT
      SROLD=SR(P)
      IF(SL(P).LT.MES(P)-.01)GO TO 203
      IF(SL(P).LT.MES(P)+.01)GO TO 205
  203 WRITE(IP1,2021)CT,PN(P)
      GO TO 9000
  205 SRT=(SL(P)-MCS(P))/(DT(1,P)-CT)
      ESP(P)=1
      IF(SRT.LT.MD(P))GO TO 210
      TE(NB1,P)=DT(1,P)
      SE(NB1,P)=1
      GO TO 50
  210 SR(P)=SRT
      SRP(P)=SR(P)-MDM(P)
      MDP(P)=MD(P)-MDM(P)
      IF(SRP(P).GE.0.)GO TO 220
      ET=7
      DO 212 I=1,NB
      BS(I,P)=0.
  212 CONTINUE
      JP=P
      DO 215 P=1,3
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      WRITE(IP1,2019)CT,PN(JP)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP3,2000)CT,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
  215 CONTINUE
      GO TO 9000
```

```
  220 CALL ALLOC(P)
      DO 225 I=1,NB
      IF(BIG(I).EQ.0)GO TO 225
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  225 CONTINUE
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      TE(NB1,P)=DT(1,P)
      SE(NB1,P)=1
      CALL NEXTEV(P)
      GO TO 50
C
C     PROCESS USER SUPPLY LEVEL FALLING BELOW SAFETY LEVEL
C
  300 WRITE(IP1,2013)CT,JE
      BSOLD=BS(JE,P)
      IF(BL(JE,P).LT.BSL(JE,P)-.01)GO TO 305
      IF(BL(JE,P).LT.BSL(JE,P)+.01)GO TO 310
  305 WRITE(IP1,2022)CT,JE,PN(P)
      GO TO 9000
  310 BP(JE,P)=1.
      SE(JE,P)=4
      CALL ALLOC(P)
      DO 320 I=1,NB
      IF(BIG(I).EQ.0)GO TO 320
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  320 CONTINUE
      IF(BSOLD.NE.BS(JE,P))WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      CALL NEXTEV(P)
      GO TO 50
C
C     PROCESS USER SUPPLY LEVEL REACHING CRITICAL LEVEL
C
  400 CONTINUE
      IW=1
      IF(BL(JE,P).LT.BCL(JE,P)-.01)GO TO 403
      IF(BL(JE,P).LT.BCL(JE,P)+.01)GO TO 405
  403 WRITE(IP1,2023)CT,JE,PN(P)
      GO TO 9000
  405 BIG(JE)=0
      DO 499 P=1,3
      BL(JE,P)=-0.
      MDOLD=MD(P)
      SROLD=SR(P)
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      WRITE(IP1,2014)CT,JE,PN(JP)
      IF(P.EQ.JP)GO TO 409
      DO 406 I=1,NB
      BL(I,P)=BL(I,P)-BIG(I)*(BR(I,P)-BS(I,P))*(CT-TLE(P))
  406 CONTINUE
      SL(P)=SL(P)-SR(P)*(CT-TLE(P))
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
  409 TLE(P)=CT
      MD(P)=MD(P)-BR(JE,P)
      MDP(P)=MD(P)-MDR(P)
      SRP(P)=SR(P)-MDR(P)
      CLOLD=CL(P)
      BS(JE,P)=0.
      BR(JE,P)=0.
```

```
      SE(JE,P)=0
      TE(JE,P)=1E9
      DO 410 I=1,NB
      IF(BIG(I).EQ.1)GO TO 420
  410 CONTINUE
      ET=7
      JP=P
      DO 416 IP=1,3
      IF(IP.EQ.JP)GO TO 413
      DO 412 I=1,NB
      BL(I,IP)=BL(I,IP)-(BR(I,IP)-BS(I,IP))*(CT-TLE(IP))
  412 CONTINUE
      SL(IP)=SL(IP)-SR(IP)*(CT-TLE(IP))
  413 IP1=3+4*IP
      IP2=4+4*IP
      IP3=5+4*IP
      IP4=6+4*IP
      WRITE(IP1,2018)CT
      WRITE(IP2,2001)CT,ET,SL(IP),(BL(I,IP),I=1,NB)
      WRITE(IP3,2000)CT,SL(IP),(BL(I,IP),I=1,NB)
      WRITE(IP4,2001)CT,ET,SR(IP),(BS(I,IP),I=1,NB)
  416 CONTINUE
      GO TO 9000
  420 IF(P.NE.JP)GO TO 561
      IF(SR(P).GE.MD(P))GO TO 430
      CALL ALLOC(P)
      DO 425 I=1,NB
      IF(BIG(I).EQ.0)GO TO 425
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  425 CONTINUE
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      CALL NEXTEV(P)
      GO TO 480
  430 DO 435 I=1,NB
      BS(I,P)=BIG(I)*BR(I,P)
      TE(I,P)=1E9
  435 CONTINUE
      SR(P)=MD(P)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      IF(SRP(P).EQ.MDP(P))GO TO 480
      SFM=(SRP(P)-MDP(P))*(DT(1,P)-CT)
      CALL SHTFAL(P)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
  480 IF(NIC(P).NE.0)GO TO 485
      WRITE(IP1,2024)CT,PN(P)
      GO TO 9000
  485 TEM=CT+CLOLD*(1./SPR(P)+1./SCL(P)+1./MSU(P)) +
     1     MSD(P)/(24.*SCS(P))+MOT(P)
      IF(DT(NIC(P),P).GT.TEM)GO TO 492
      NIC1=NIC(P)+1
      DO 490 J=NIC1,NTC(P)
      IF(DT(J,P).GE.TEM)GO TO 492
      NIC(P)=NIC(P)+1
  490 CONTINUE
  492 CALL REVISE(P)
      NTC(P)=NIC(P)+NC(P)+1
      NC1=NC(P)+1
      DO 493 J=1,NC1
      DT(NIC(P)+J,P)=DT(NIC(P),P)+J*TR(P)
      DC(NIC(P)+J,P)=CL(P)
  493 CONTINUE
```

```
      IJ=0
      IF(NCO.GT.NOC)GO TO 498
      K=NCO
  494 DO 495 J=K,NOC
      IF(CUN(J).EQ.JE)GO TO 496
      IJ=1
  495 CONTINUE
      GO TO 498
  496 NOC=NOC-1
      IF(J.GT.NOC)GO TO 498
      DO 497 JJ=J,NOC
      CUN(JJ)=CUN(JJ+1)
      TC(JJ)=TC(JJ+1)
      DO 4790 IP=1,3
      CUD(JJ,IP)=CUD(JJ+1,IP)
      CUP(JJ,IP)=CUP(JJ+1,IP)
 4790 CONTINUE
  497 CONTINUE
      K=J
      GO TO 494
  498 CONTINUE
      TEM1=1E9
      IF(IJ.NE.0)TEM1=TC(NCO)
      DO 4990 IP=1,3
 4990 TE(NB2,IP)=TEM1
  499 CONTINUE
      IW=0
      GO TO 50
C
C     PROCESS CONTINGENCY EVENT
C
  500 JE=CUN(NCO)
      IC=IC+1
      MDOLD=MD(P)
      SROLD=SR(P)
      MD(P)=MD(P)-BR(JE,P)+CUD(NCO,P)
      BR(JE,P)=CUD(NCO,P)
      BPOLD=BIP(JE,P)
      BIP(JE,P)=CUP(NCO,P)
      IF(SE(JE,P).NE.4)BP(JE,P)=BIP(JE,P)
      TE(NB2,P)=1E9
      IF(IC.NE.3)GO TO 504
      IC=0
      NCO=NCO+1
      NCO1=NCO
      IF(NCO1.GT.NOC)GO TO 503
      DO 501 N=NCO1,NOC
      JT=CUN(N)
      IF(BIG(JT).NE.0)GO TO 502
      NCO=NCO+1
  501 CONTINUE
  502 IF(NCO.GT.NOC)GO TO 503
      DO 5020 KP=1,3
      TE(NB2,KP)=TC(NCO)
 5020 CONTINUE
      GO TO 504
  503 DO 5030 KP=1,3
      TE(NB2,KP)=1E9
 5030 CONTINUE
  504 CLOLD=CL(P)
      IF(MD(P)-MDOLD)560,550,520
```

```
  520 CALL REVISE(P)
      WRITE(IP1,2015)CT,JE
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      IF(ESP(P).NE.0)GO TO 542
      SR(P)=MD(P)
      BS(JE,P)=BR(JE,P)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
  522 CONTINUE
      TFA=CT+SCC(P)*(1./SPR(P)+1./SCL(P)+1./MSU(P)) +
     1     MSD(P)/(24.*SCS(P))+MOT(P)
      NIC(P)=0
      TEM=CT+CLOLD*(1./SPR(P)+1./SCL(P)+1./MSU(P)) +
     1     MSD(P)/(24.*SCS(P))+MOT(P)
      DO 525 J=1,NTC(P)
      IF(DT(J,P).GE.TEM)GO TO 526
      NIC(P)=NIC(P)+1
  525 CONTINUE
  526 TSA=DT(NIC(P)+1,P)
      CLP=DC(NIC(P)+1,P)
      CAR=CLP+(MD(P)-MDOLD)*(TSA-CT)
      TEM=(CAR-MD(P)*(TSA-TFA))/SCC(P)
      ITEM=INT(TEM)
      REM=TEM-1.*ITEM
      IF(REM.GT.0.)ITEM=ITEM+1
      TLA=TSA-(CAR-ITEM*SCC(P))/MD(P)
      IF(REM.GT.0.)GO TO 529
      DO 528 J=1,ITEM
      DT(NIC(P)+J,P)=TFA+(J-1)*.001
      DC(NIC(P)+J,P)=SCC(P)
  528 CONTINUE
      NIC(P)=NIC(P)+ITEM
      GO TO 536
  529 IF(ITEM.GT.1)GO TO 531
      IF(NIC(P).EQ.0)GO TO 530
      TL=DT(NIC(P),P)
      GO TO 533
  530 TL=CT-(MSC(P)-SL(P))/MD(P)
      GO TO 533
  531 IT1=ITEM-1
      DO 532 J=1,IT1
      DT(NIC(P)+J,P)=TFA+(J-1)*.001
      DC(NIC(P)+J,P)=SCC(P)
  532 CONTINUE
      TL=TFA
  533 IF((TLA-TL).GE.TR(P))GO TO 534
      DT(NIC(P)+ITEM,P)=TLA
      DC(NIC(P)+ITEM,P)=SCC(P)
      GO TO 535
  534 TEM=AMAX1(TL+TR(P),TFA)
      DT(NIC(P)+ITEM,P)=TEM
      DC(NIC(P)+ITEM,P)=SCC(P)-MD(P)*(TLA-TEM)
  535 NIC(P)=NIC(P)+ITEM
  536 NC1=NC(P)+1
      DO 537 J=1,NC1
      DT(NIC(P)+J,P)=DT(NIC(P),P)+J*TR(P)
      DC(NIC(P)+J,P)=CL(P)
  537 CONTINUE
      NTC(P)=NIC(P)+NC(P)+1
      IF(ESP(P).EQ.1)GO TO 539
      TEM=CT+(SL(P)-MES(P))/MD(P)
      IF(TEM.GE.DT(1,P))GO TO 538
```

```
      SE(NB1,P)=2
      TE(NB1,P)=TEM
      GO TO 50
  538 SE(NB1,P)=1
      TE(NB1,P)=DT(1,P)
      GO TO 50
  539 SE(NB1,P)=1
      TE(NB1,P)=DT(1,P)
      GO TO 50
  542 SRT=(SL(P)-MCS(P))/(DT(1,P)-CT)
      IF(SRT.LT.MD(P))GO TO 545
      SR(P)=MD(P)
      BS(JE,P)=BR(JE,P)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      GO TO 522
  545 SR(P)=SRT
      SRP(P)=SR(P)-MDR(P)
      MDP(P)=MD(P)-MDR(P)
      CALL ALLOC(P)
      DO 548 I=1,NB
      IF(BIG(I).EQ.0)GO TO 548
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  548 CONTINUE
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      CALL NEXTEV(P)
      GO TO 522
  550 IF(BIP(JE,P).EQ.BPOLD)GO TO 50
      WRITE(IP1,2015)CT,JE
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      IF(ESP(P).EQ.0)GO TO 50
      IF(SR(P).EQ.MD(P))GO TO 50
      IF(SE(JE,P).EQ.4)GO TO 50
      SRP(P)=SR(P)-MDR(P)
      MDP(P)=MD(P)-MDR(P)
      CALL ALLOC(P)
      DO 555 I=1,NB
      IF(BIG(I).EQ.0)GO TO 555
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  555 CONTINUE
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      CALL NEXTEV(P)
      GO TO 50
  560 CONTINUE
      WRITE(IP1,2015)CT,JE
  561 CALL REVISE(P)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      IF(ESP(P).NE.0)GO TO 585
      SR(P)=MD(P)
      BS(JE,P)=BR(JE,P)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
  562 CONTINUE
      NIC(P)=0
      TEM=CT+CLOUD*(1./SPR(P)+1./SCL(P)+1./MSU(P)) +
     1    MSD(P)/(24.*SCS(P))+MOT(P)
      DO 564 J=1,NTC(P)
      IF(DT(J,P).GE.TEM)GO TO 565
      NIC(P)=NIC(P)+1
  564 CONTINUE
  565 IF(NIC(P).EQ.0)GO TO 566
      TL=DT(NIC(P),P)
      TN=DT(NIC(P)+1,P)
```

```
      CLI=DC(NIC(P)+1,P)
      GO TO 568
  566 TL=CT
      TN=DT(1,P)
      CLI=DC(1,P)
  568 NIC(P)=NIC(P)+1
      DELT=TN-TL
      SOF=(MDOLD-MD(P))*DELT
      IF(NIC(P).EQ.1)TL=CT-(MSC(P)-SL(P))/MD(P)
      TPA=TN+(SOF+SCC(P)-CLI)/MD(P)
      IF((TPA-TL).GT.TR(P))GO TO 572
      DT(NIC(P),P)=TPA
      DC(NIC(P),P)=SCC(P)
      GO TO 580
  572 TFA=(CT+(SCC(P)-TPA*MD(P))*(1./SPR(P)+1./SCL(P)+1./MSU(P)) +
     1  MSD(P)/(24.*SCS(P))+MOT(P))
     2 /(1.-MD(P)*(1./SPR(P)+1./SCL(P)+1./MSU(P)))
      IF((TFA-TL).GT.TR(P))GO TO 574
      DT(NIC(P),P)=TL+TR(P)
      DC(NIC(P),P)=SCC(P)-(TPA-TR(P)-TL)*MD(P)
      GO TO 580
  574 DT(NIC(P),P)=TFA
      DC(NIC(P),P)=SCC(P)-(TPA-TFA)*MD(P)
  580 NC1=NC(P)+1
      NTC(P)=NIC(P)+NC(P)+1
      DO 582 J=1,NC1
      DT(NIC(P)+J,P)=DT(NIC(P),P)+J*TR(P)
      DC(NIC(P)+J,P)=CL(P)
  582 CONTINUE
      IF(ESP(P).NE.0)GO TO 584
      TEM=CT+(SL(P)-MES(P))/MD(P)
      IF(TEM.GE.DT(1,P))GO TO 584
      SE(NB1,P)=2
      TE(NB1,P)=TEM
      IF(IW.EQ.1)GO TO 499
      GO TO 50
  584 SE(NB1,P)=1
      TE(NB1,P)=DT(1,P)
      IF(IW.EQ.1)GO TO 499
      GO TO 50
  585 SRT=(SL(P)-MCS(P))/(DT(1,P)-CT)
      IF(SR(P).GE.MDOLD)GO TO 590
      IF(SRT.GE.MD(P))GO TO 588
      SR(P)=SRT
      SRP(P)=SR(P)-MDR(P)
      MDP(P)=MD(P)-MDR(P)
      CALL ALLOC(P)
      DO 587 I=1,NB
      IF(BIG(I).EQ.0)GO TO 587
      BS(I,P)=BR(I,P)-WB(I)*(MDP(P)-SRP(P))
  587 CONTINUE
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      CALL NEXTEV(P)
      GO TO 562
  588 DO 589 I=1,NB
      BS(I,P)=BIG(I)*BR(I,P)
      TE(I,P)=1E9
  589 CONTINUE
      IF(SRT.GT.MD(P))GO TO 590
      SR(P)=MD(P)
      BS(JE,P)=BR(JE,P)
```

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      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      GO TO 562
  590 SR(P)=MD(P)
      BS(JE,P)=BR(JE,P)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
      SFM=(SRT-SR(P))*(DT(1,P)-CT)

      DO 592 I=1,NB
      IF(SE(I,P).NE.0)GO TO 595
  592 CONTINUE
      GO TO 562
  595 CALL SHTFAL(P)
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
      GO TO 562
C
C     PROCESS SCHEDULED PRINT OUT
C
  600 TE(NB3,P)=CT+TP

      IF(TE(NB3,P).LT.TDUR)GO TO 610
      TE(NB3,P)=TDUR
      SE(NB3,P)=7
  610 WRITE(IP3,2000)CT,SL(P),(BL(I,P),I=1,NB)
      GO TO 50
C
C     PROCESS SCHEDULED RUN TERMINATION
C
  700 DO 710 P=1,3
      IP1=3+4*P
      IP2=4+4*P
      IP3=5+4*P
      IP4=6+4*P
      IF(P.EQ.JP)GO TO 708
      DO 702 I=1,NB
      BL(I,P)=BL(I,P)-(BR(I,P)-BS(I,P))*(CT-TLE(P))
  702 CONTINUE
      SL(P)=SL(P)-SR(P)*(CT-TLE(P))
      WRITE(IP2,2001)CT,ET,SL(P),(BL(I,P),I=1,NB)
  708 WRITE(IP1,2017)CT
      WRITE(IP3,2000)CT,SL(P),(BL(I,P),I=1,NB)
      WRITE(IP4,2001)CT,ET,SR(P),(BS(I,P),I=1,NB)
  710 CONTINUE
      GO TO 9000
  900 WRITE(IP1,2025)
 9000 CONTINUE
C  *****COPY OUTPUT FILES IN SEQUENCE TO OUTPUT******
      REWIND 8
      REWIND 9
      REWIND 10
      REWIND 11
      REWIND 12
      REWIND 13
      REWIND 14
      REWIND 15
      REWIND 16
      REWIND 17
      REWIND 18
 9100 READ(8,1005,ERR=9200,END=9200)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9100
 9200 READ(9,1005,ERR=9300,END=9300)(MK(K),K=1,132)
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      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9200
 9300 READ(10,1005,ERR=9400,END=9400)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9300
 9400 READ(11,1005,ERR=9401,END=9401)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9400
 9401 READ(12,1005,ERR=9402,END=9402)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9401
 9402 READ(13,1005,ERR=9403,END=9403)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9402
 9403 READ(14,1005,ERR=9404,END=9404)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9403
 9404 READ(15,1005,ERR=9405,END=9405)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9404
 9405 READ(16,1005,ERR=9406,END=9406)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9405
 9406 READ(17,1005,ERR=9407,END=9407)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9406
 9407 READ(18,1005,ERR=9900,END=9900)(MK(K),K=1,132)
      WRITE(7,1005)(MK(K),K=1,132)
      GO TO 9407
 9900 STOP
      END
      SUBROUTINE REVISE(P)
      COMMON /BLOCK1/ TCM,MSC(3),MES(3),MD(3),SCC(3),TR(3),
     1                CL(3),TCY(3),TCP,SPR(3),SCL(3),
     2                MSU(3),NC(3)
      REAL   MD,MSC,MSU,MES
      INTEGER P
      TCM=(MSC(P)-MES(P))/MD(P)
      TEM=SCC(P)/MD(P)
      IF(TEM.GT.TCM)GO TO 10
      TR(P)=TEM
      CL(P)=SCC(P)
      TCP=TCY(P)
      GO TO 20
   10 TR(P)=TCM
      CL(P)=TR(P)*MD(P)
      TCP=TCY(P)-(SCC(P)-CL(P))*(1./SPR(P)+1./SCL(P)+1./MSU(P))
   20 TEM=TCP/TR(P)
      NC(P)=INT(TEM)
      REM=TEM-1.*NC(P)
      IF(REM.GT.0.)NC(P)=NC(P)+1
      RETURN
      END
      SUBROUTINE NEXTEV(P)
      COMMON /BLOCK2/ NB,BIG(10),SE(13,3),TE(13,3),BL(10,3),BSL(10,3),
```

```
     1    BML(10,3),BCL(10,3),BR(10,3),BIR(10,3),BS(10,3),BP(10,3),
     2     BIP(10,3),WB(10),SL(3),SFM,CT
      INTEGER SE,BIG,P
      DO 10 I=1,NB
      IF(BIG(I).EQ.0)GO TO 10
      IF(SE(I,P).EQ.4)GO TO 5
      SE(I,P)=3
      TE(I,P)=CT+(BL(I,P)-BSL(I,P))/(BR(I,P)-BS(I,P))
      GO TO 10
    5 TE(I,P)=CT+(BL(I,P)-BCL(I,P))/(BR(I,P)-BS(I,P))
   10 CONTINUE
      RETURN
      END
      SUBROUTINE ALLOC(P)
      COMMON /BLOCK2/ NB,BIG(10),SE(13,3),TE(13,3),BL(10,3),BSL(10,3),
     1    BML(10,3),BCL(10,3),BR(10,3),BIR(10,3),BS(10,3),BP(10,3),
     2     BIP(10,3),WB(10),SL(3),SFM,CT
      INTEGER    SE,BIG,P
      DIMENSION B(10)
      PRO=1.
      DO 10 I=1,NB
      IF(BIG(I).EQ.0)GO TO 10
      B(I)=BP(I,P)/BR(I,P)
      PRO=PRO*B(I)
   10 CONTINUE
      SUM=0.
      DO 20 I=1,NB
      IF(BIG(I).EQ.0)GO TO 20
      WB(I)=PRO/B(I)
      SUM= SUM+WB(I)
   20 CONTINUE
      DO 30 I=1,NB
      IF(BIG(I).EQ.0)GO TO 30
      WB(I)=WB(I)/SUM
   30 CONTINUE
      RETURN
      END
      SUBROUTINE SHTFAL(P)
      COMMON /BLOCK2/ NB,BIG(10),SE(13,3),TE(13,3),BL(10,3),BSL(10,3),
     1    BML(10,3),BCL(10,3),BR(10,3),BIR(10,3),BS(10,3),BP(10,3),
     2     BIP(10,3),WB(10),SL(3),SFM,CT
      INTEGER    SE,BIG,P
      DIMENSION SF(10)
      DO 10 I=1,NB
      IF(BIG(I).EQ.0)GO TO 10
      IF(SE(I,P).EQ.4)GO TO 20
   10 CONTINUE
      GO TO 80
   20 SSF=0.
      DO 30 I=1,NB
      IF(SE(I,P).NE.4)GO TO 29
      SF(I)=BSL(I,P)-BL(I,P)
      SSF=SSF+SF(I)
      GO TO 30
   29 SF(I)=0.
   30 CONTINUE
      IF(SFM.GE.SSF)GO TO 50
      DO 45 I=1,NB
      BL(I,P)=BL(I,P)+SF(I)*SFM/SSF
   45 CONTINUE
      SL(P)=SL(P)-SFM
```

```
      RETURN
   50 DO 60 I=1,NB
      IF(SF(I).EQ.0.)GO TO 60
      BL(I,P)=BSL(I,P)
      SFM=SFM-SF(I)
      SL(P)=SL(P)-SF(I)
   60 CONTINUE
      IF(SFM.LE.0.)RETURN
      DO 70 I=1,NB
      IF(SE(I,P).NE.4)GO TO 70
      SE(I,P)=3
      BP(I,P)=BIP(I,P)
   70 CONTINUE
   80 SSF=0.
      DO 90 I=1,NB
      IF(SE(I,P).NE.3)GO TO 85
      SF(I)=BML(I,P)-BL(I,P)
      SSF=SSF+SF(I)
      GO TO 90
   85 SF(I)=0.
   90 CONTINUE
      IF(SFM.LT.SSF)GO TO 120
      DO 110 I=1,NB
      IF(SF(I).EQ.0.)GO TO 110
      BL(I,P)=BML(I,P)
      SE(I,P)=0
      SL(P)=SL(P)-SF(I)
  110 CONTINUE
      RETURN
  120 DO 130 I=1,NB
      IF(BIG(I).EQ.0)GO TO 130
      BL(I,P)=BL(I,P)+SF(I)*SFM/SSF
  130 CONTINUE
      SL(P)=SL(P)-SFM
      RETURN
      END
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